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SMALL MOTIVE POWER.

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From Selected Papers of the Institution of Civil Engineers.

II.

AIR.

After some long and thorough trials on a large scale of hot-air engines, the most important of which were at the Dundee Foundry, about 1845,* and on the ship Ericsson, 1852, hot air has been universally acknowledged to be adapted only to perform operations requiring but little power, its present application in this country being almost entirely confined to the immediate supersession of hand labor. The hot-air engine has, however, a high efficiency, and in the first of the above cases, Mr. J. Stirling, the son of the original inventor, stated that the Stirling engine, then described, used only 2½ pounds of coal per hour per HP., which was said to be ⅓ of that used by the best steam engines of the day; and in the discussion which followed, the author stated that he had "every reasonable confidence in its ultimate success." Again, in the second case in which Ericsson's engine was used, the action of which is described by Professor Rankine,† the consumption of anthracite was 1.87 pound per hour per HP., where, "notwithstanding the low efficiency of the furnace, ... the efficiency of the fluid was so great as to give a resultant efficiency superior to that of almost all steam engines at the time of the experiments referred to." In spite of these facts, it was not till a few years ago that small hot-air engines had any considerable use in this country. The reason for this has been already referred to—the high temperatures required, and the narrow range of effective pressure; the latter rendering bulky apparatus necessary to produce much power, the former rendering the mechanical difficulties in dealing with that apparatus very great, as, for instance, the permeation of the glowing fire box by the air under compression, which it has been proved takes place. Now, however, there are several successful patents for hot-air engines whose great recommendation is the absolute freedom from danger of explosion, and almost noiseless action, together with a high efficiency. There are two kinds of engines which, according to the method of using the working fluid, are called "closed" or "open." The two engines above mentioned are prototypes of these two classes. In the Stirling engine the same mass of air under pressure was used continuously, and by alternate heating and cooling was made to do work; it is therefore called "closed." In the Ericsson engine

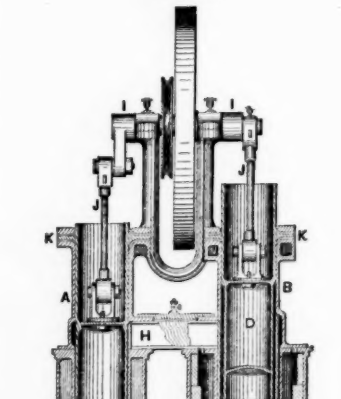
* *Vide* Minutes of Proceedings Inst. C. E., vol. iv., page 348.

† "A manual of the Steam Engine and other Prime Movers," 8th ed., p. 361.

a fresh supply of air was taken in by the engine at every stroke, in a similar way to steam from a boiler, and after doing work by the application of heat, was rejected in a similar way to steam; it is therefore called "open." With regard to the latter, little will be said; for as far as the author is able to learn, they are scarcely if at all used in this country. In Germany the open engine of Hock, and in France that of Belou, give satisfactory results, but these differ in an important point from the Ericsson engine, the air not being heated by mere contact with a metallic surface, but being made to pass through the fire and support combustion, thus bearing a resemblance to the action of gas engines. In a trial of the Belou engine at Cusset, quoted by Mr. D. K. Clark (p. 918, "Rules and Tables"), the consumption of coal was 0.735 pounds per hour per I.HP., and 3.24 pounds per net HP. at the brake. In a trial of a Hock engine by Professor Jenny, of the Imperial Technological School of Vienna,* 7 kilogrammes of coke were used in sixty-three minutes by an engine developing 1.58 HP. at the brake, which is almost exactly equivalent to $9\frac{1}{4}$ pounds of coke per hour per HP. These results compare favorably with the work done by most closed air engines, but the Belou engine was of large size—of more than 27 HP.; and it is the Hock engine, or one similar to it, which is of low first cost, and has many advantages, that must be regarded as the one whose introduction might profitably take place, and which is spoken very highly of in the report referred to.

Closed air engines are numerous; those of Laubereau, Lehmann, Stenberg (the Calorisca), D. van Rennes, and Rider being the principal. With each there is some difference in theory, as shown by Dr. A. Slaby.† A distinction can, however, be made between single and double-acting engines. Laubereau's, which is a modification of Stirling's, is commonly used in France; while in Germany Lehmann's is most popular, as testified by the fact that over a thousand are there in use. Both Lehmann's and Stenberg's have a brickwork erection at the end distant from the crank shaft, and, being horizontal, considerable space is necessary. While the machinery of Lehmann's is decidedly complicated, Laubereau's is vertical, and very compact and portable, and, in spite of the alleged defect pointed out by Dr. Slaby, which is avoided in Lehmann's engine, viz., that the heating chamber communicates directly with the working piston, and so renders the packing liable to rapid deterioration, it has worked satisfactorily, using, in a trial quoted by Mr. D. K. Clark, 4.8 pounds of coal per hour per HP., and 11 pounds per HP. at the brake. Lehmann's engine has been recently introduced into this country, and was awarded the first prize at the Manchester and Liverpool Show, 1879; but at present the engine most generally

Fig. 11.



used is that of Rider, of which, since its introduction from America three years ago, upwards of nine hundred have been sold; therefore, of this only will a description be given. Fig. 11 is a sectional view taken from the prospectus of the company; it is there seen to be single-acting, and to consist of two cylinders, A and B, in which two vertical hollow

* Klein-Kraft-Maschinen," p. 42.
† *Vide* Minutes of Proceedings Inst. C. E., vol., p. 370.

plungers, C and D, work air-tight for a portion of their length, driving cranks set at 95° on the shaft above. The method of packing is most ingenious, consisting of two reversed leather collars, which seem to wear satisfactorily, although in direct communication with the heating chamber. A is the cooling or compression cylinder, in which, by the device of an annulus of air between the plunger and casing E, round which water circulates, a rapid cooling can be effected; and in the same way an annulus of air in the other, or working cylinder B, enables a rapid transfer of heat to take place when this is necessary. The action is as follows: When the air in C is compressed by hand at starting to about $\frac{1}{3}$ its original volume, the rising of the piston B, which is of equal area, enables it to be transferred without change of volume to that cylinder with which there is a communication. Here the heating, which is facilitated by the shape of the bottom of the plunger, takes place, and the consequent expansion causes the continuance of the upstroke of D. Upon the return stroke of D, the air is transferred to the compression cylinder, but is made on the way to give up heat to the thin plates in the regenerator H, of which a partial view is shown, and this heat is restored when the repetition of the first operation takes place; the rest of the heat which must be abstracted is taken away by the water in the casing, and the engine now continues to work, the difference between the positive work in the working cylinder, and the negative work in the compression cylinder being the effective work. The $\frac{1}{2}$-HP. engine has been found to consume 4 pounds of coke per hour; the 1-HP. a little more than twice that amount. One was tested at the Royal Agricultural Show at Birmingham, and the work done by pumping showed a consumption of 13 pounds of coal per hour per HP., or a little more than $\frac{1}{4}$ that used by the pulsometer pump, or $\frac{1}{3}$ of that in the Tangye pump, in the experiments already referred to. The cost of coal for a week's work of six days, working ten hours a day, is advertised not to exceed 2*s.* 6*d.* for a $\frac{1}{2}$-HP. engine. These engines are thus economical; they are reliable and simple in action, and require no skilled attendant; they are safe, and, in pumping operations, for which they are usually applied, the water pumped can be made to circulate in the casing, and so act as a cooler; but, in common with nearly all hot-air engines, they are heavy in proportion to their power. Hot-air engines, then, have decided advantages, and in the country their employment might, and probably will be, profitably extended.

Compressed air has been applied to transmit power for a variety of objects; but the purpose for which, on a small scale, it seems specially adapted, is to supersede manual and animal labor in rock boring and mining operations. For mine and tunnels there are many advantages attending its use; for not only is the air which is compressed by external machinery of great importance for ventilation, but the fall in temperature by expansion, which accompanies the necessary loss of heat occasioned by its use, is valuable, as tending to reduce the temperature in close and heated workings. The principal objects to which it is put are for underground haulage, pumping, and rock boring or coal-cutting operations. The first of these has been considered by Mr. W. Daniel, in a paper before the Institution of Mechanical Engineers,* and is rather applied to motors of a size not here dealt with; the second may use any of the ordinary steam pumps; but it is the last which is particularly an example of the successful application of machinery to replace individual physical effort. A vast amount of attention and ingenuity have been bestowed upon rock-boring and coal-cutting apparatus, of which drilling shot holes in the former is the most important and toilsome part of the labor required, and one to which the application of motive power has been most beneficial. Only one form of rock borer will be described, but one which, at the Bristol docks, has proved efficient and durable. Figs. 12 and 13 are two views of the drill of R. Schram; the action simply imitates that of hand boring, viz., a succession of blows, accompanied by a turning motion. The machine consists of a strong cylinder supported by three legs, in which works a solid piston rod, driven by a double piston, the end of the rod carrying the

* *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 204.

drill. The blows are given as rapidly as 400 or 500 per minute, by means of the valve *f f*, which acts in a somewhat similar way to that of the special pump; when the opening *o*, shown by dotted lines, in the cylinder is open to the pressure of the air, the opposite end of the valve will be also under pressure, and will remain in one position; but directly it is opened to the exhaust, by the edge of the piston passing it, the end of the valve will also be opened to the exhaust, the pressure removed, and the valve thrown over, and the action on the piston reversed.

Fig. 12.

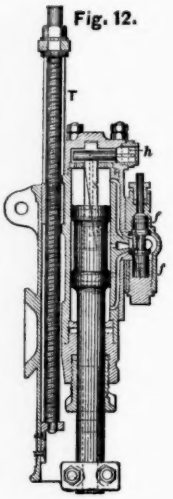
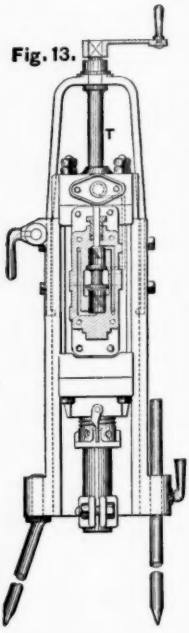


Fig. 13.



Similarly for the opening *o'*, communicating with the other end of the valve. The second action, or turning, is effected by means of a small piston *p*, shown in section, Fig. 13, which acts at right angles to the stroke of the drill, but is not quite in the same center line, and therefore every stroke it takes will turn the ratchet wheel *w*, which is in that line, and, consequently, the position of a spiral rod *s* fitting into the end of the piston rod. This happens when the drill is down, and the spiral rod free from it; but when the drill and piston rod make the in-stroke, the spiral rod running into the former, and being itself held firmly, turns it through the necessary angle; in the out-stroke no turning takes place. The feeding is effected by the hand-screw T.

It is well known that compressed air necessarily involves considerable loss, from the fact that most of the heat developed by compression cannot at present be retained, so as to act when the converse expansion takes place in the motor. This subject has been fully treated, both theoretically and experimentally, by many engineers, especially in France. From Mr. Robinson's paper,* already referred to, the total loss appears to be never in practice less than 50 per cent. of the energy used in compression, and sometimes as much as 75 per cent. Again, the result of some experiments by Mr. W. Daniel shows a loss† from 54.2 per cent., with 19 pounds per square inch air pressure, to 74.2 with 40 pounds air pressure.

But the work lost is more than compensated for by the attendant advantages, and where, as in the Mont Cenis tunnel, a natural head of water can be employed, it must be superior to all other agents; though for purposes above ground, notwithstanding several attempts to introduce it, and except in the Westinghouse brake, the loss with compressed air is sufficient to prevent its general adoption, and even rock-boring drills are then worked by steam.

WATER.

A natural head of water was, perhaps, the first power applied to take the place of manual labor, and though used all over the world on a large scale, and in Switzerland and some other countries for small powers—where mountain streams are employed even for such domestic purposes as churning and rocking cradles—yet in this country the extension of small water motors has been confined almost entirely to towns having artificial sources of supply. Nevertheless, as has been forcibly brought forward on several occasions of late, the natural power at

* *Vide* Minutes of Proceedings Inst. C. E., vol. xlix., p. 17 *et seq.*

† *Vide* Institution of Mechanical Engineers. Proceedings, 1874, p. 210.

present running to waste might, by means of more efficient transmitting agencies, be taken advantage of. There are several instances in which this is being done, as at Tortona, in Italy, where, since 1876, the force of the torrent Servia has been made to supersede steam by applying telodynamic transmission, and a daily saving of 60 per cent. in cost thereby effected.* Again, on the estates of M. Menier, the power derived from the river Marne is used, by means of electric transmission, for ploughing and other agricultural purposes, and it is proposed to extend it to a distance of 3 miles from the source. Also, in America the use of the almost boundless supply of natural head of water is being rapidly extended for similar labor-saving objects; but it is a significant fact with regard to this country, that although Sir W. Armstrong, who, if not the first, has certainly been the chief, engineer in introducing the present hydraulic system, was led to the subject by noticing the waste above referred to. His first idea, like that of many others, was to prevent that waste, and he has established a magnificent system, not, however, based upon the use of the natural source of power, but upon a source whose essential principle is the production of an artificial head of water—in most cases by the use of steam. The fact is, that the supply of power referred to must be turned into work at its source, or stored up under a, so to speak, higher pressure; since, when it is the power of the water, and not the water itself that is required, the proportional loss by transmission would otherwise render its use impracticable. Now the obvious advantages to small industries from localization seems to account for the undoubted tendency in this country to cary on small manufactories in towns, to which the power must be conveyed: therefore, their connection with the natural source is an important problem, the solution of which necessitates (1) an abundant supply, and (2) an efficient means of transmission. England cannot be said to be rich in the former, and the latter is far from being in a satisfactory or settled state; so that, until the want of fuel is more keenly felt, artificial sources will in towns, no doubt, continue to be principally used. Still in the country small water wheels, or turbines, are often conveniently applied, and many of the former have been erected by Mr. W. Anderson, M. Inst. C. E. (of the firm of Messrs. Easton and Anderson), of 0.018, 0.04, 0.26, &c., HP., chiefly for pumping purposes.*

The two sources of water power in a town are:

(1) The reservoirs for supplying water for domestic purposes.

(2) The accumulators specially erected for obtaining a head of water.

Up to the year 1849 the supply in towns was drawn from reservoirs, and it was one of the original ideas, set forth in a letter by Sir W. Armstrong, F.R.S., V.-P. Inst. C.E., to the Mechanics' Magazine," and referred to by him in a paper before the Institution,† that "the water already supplied to towns for domestic purposes could in many cases be advantageously employed for working cranes, printing presses, and in short, all kinds of machines where manual labor was usually employed." This is an artificial source, since steam engines are generally employed to raise the water into the reservoirs. The expense, however, is a serious consideration, for it must be remembered that the water is supplied for a different purpose, and the head is only made sufficiently great to distribute the water to the summit of the various buildings, and in London, for instance, it is not even so great as that. Besides being small, the pressure is found to vary considerably, and not only by diurnal changes, due to reasonable causes—it being, for example, 45 pounds per square inch at Westminster in the morning, and rising to somewhat over 60 pounds in the afternoon, and in Bristol from 40 pounds to 70 pounds—but also to sudden and erratic changes, most trying to the water motor employed. The consumer is, nevertheless, charged for the quantity used, independently of the pressure; and as inquiry seems to indicate that this is often highest in the towns where the average pressure is lowest, the system must be far from satisfactory. These causes no doubt led to

* *Vide* Minutes of Proceedings Inst. C. E., vol. 1., p. 192.

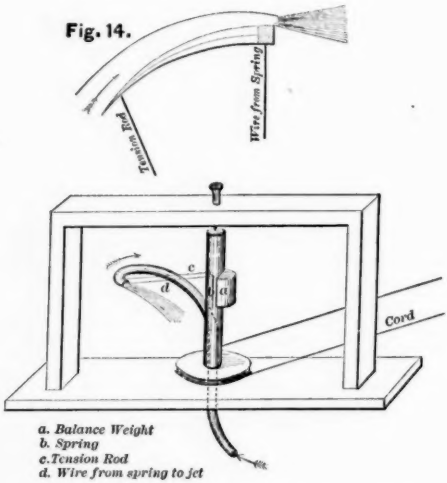
* *Vide* Transactions Inst. C. E. of Ireland, vol. ix., p. 78.

† *Vide* Minutes of Proceedings Inst. C.E., vol. 1., p. 66.

the second method, viz., the use of the accumulator for supplying water under considerable pressure, which brought out the advantages of water as an agent, and showed its superiority under great pressures, from its incompressible nature, which both renders it capable of transmitting great power and at the same time obviates all danger from explosion; and the size of the motor can be so reduced as to render the amount of water used but trifling. The pressure under which the water is used has everything to do with the kind of motor employed; and before comparing the cost of the two foregoing modes of supply, the types of apparatus must be discussed.

No doubt the motors giving the highest efficiency, under proper conditions, are turbines and reaction wheels, but these conditions are such as to exclude them for water under much pressure, and even with water from the mains the use of the former is practically out of the question, for the linear velocity of the rim of the wheel should bear some ratio to the velocity due to that pressure, and as the size of the wheel diminishes, its number of revolutions must, for a constant head of water, increase; so that to obtain any reasonable efficiency, the velocity for a very small wheel would have to be as much as 4,000 or 5,000 revolutions per minute. The inward-flow turbine of Professor James Thomson is made to very small sizes; but in a letter to the author the inventor says: "I do not recommend any kind of turbines for ordinary use with very small water supplies and high-water pressures." The reaction wheel can be made to work economically up to moderately high pressures, because the radius of its discharge orifices can be increased, and so the law connecting the head with the linear velocity of the jet (which is velocity $=8\sqrt{h}$) can be nearly satisfied. In a paper read by Mr. W. C. Kernot, M. A., C. E.,* at Melbourne, a small motor of this kind, shown in Fig. 14, is advocated, in which, by means of a counterweight *a*, one arm is dispensed with, and the hydraulic radius doubled, all sharp bends are avoided, and, as a result of experiment, with a consumption of 2.8 gallons of water per minute (at 1*s.* per 1,000 gallons), pressure by gauge 75 pounds per square inch, speed of 1,300 revolutions per minute; 0.055 HP. were obtained to drive a small lathe, the efficiency being 40 per cent. An ingenious form of governor was used, in which the increased speed by the centrifugal force of a weight, closed the orifice of escape and acted most effectually to check the

Fig. 14.



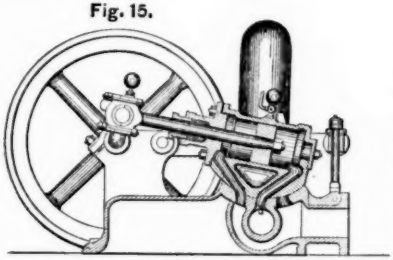
a. Balance Weight
b. Spring
c. Tension Rod
d. Wire from spring to jet

* Notes on Small Motors. Royal Society of Victoria, Oct. 9, 1879.

racing and variation in speed, reducing the water used from 2.8 gallons per minute in full work, to 0.75 gallon when all the machinery was disconnected. There are numberless cases in which such a motor as the foregoing might be advantageously employed in towns, and where its use would compare favorably in efficiency with some of the engines at present chiefly employed and known as "water-pressure engines."

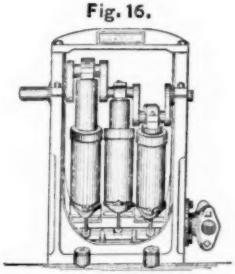
The form of water-pressure engine which is almost universally adopted for obtaining rotary motion is the oscillating type. A sectional view is shown in Fig. 15 of Haags' engine, which is ex-

Fig. 15.



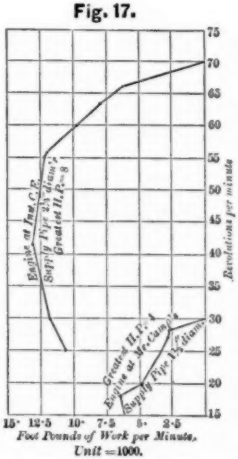
tensively used on the continent, and is largely supplied by Schmid, of Zurich, where small water motors are used to the number of one hundred and thirteen, as alluded to by Mr. E. Matheson, M. Inst. C. E.* The action of the engine is extremely simple. The oscillation of the cylinder about its center alternately opens the opposite ends of the cylinder to the supply and exhaust of water. There seems to be a large amount of clearance by the long ports which would entail waste, but otherwise the engine is cheap and efficient. It is being introduced into this country by Messrs. Bailey and Co., of Manchester. Another form is Rambottom's patent, of which a general view is shown in Fig. 16. This, from its small first cost and simplicity of action, is at present the most extensively used in this country. Three cylinders oscillate about their lower extremities, and work upon a hollow cast-iron pipe, which is divided into two parts by a vertical diametral partition running its whole length. One side conveys the water under pressure to the cylinders by ports, which, when the cylinders are in an inclined position, communicate with corresponding ports in their basis; in a

Fig. 16.



similar manner the other side conveys away the water when the cylinder is inclined in the opposite direction. Experiments were made with a dynamometer upon two of these, through the kindness of Mr. Camp, of Bristol, the inventor of hair brushing machinery, and which was used for that purpose, the other being erected at The Institution of Civil Engineers, Great George Street, for driving

Fig. 17.



the ventilating and warming apparatus. The annexed table gives a tabulated result of the experiments, from which the curves (Fig. 17) have been constructed.

* *Vide* Minutes of Proceedings Inst. C. E., vol. xlix. p. 35.

The pressure of the water gauge was taken with every change of load on the dynamometer; but since the gauge was fitted by a pipe at right angles to the pipe, and some feet from the engine, it would not be right to assume this as the pressure in the cylinders; the flow of water past an orifice being well known to affect the pressure in a channel from that orifice. Therefore, no deductions are drawn as to the efficiency of the motors at any but the lowest speed; for it was found that the cylinders, according to the reading of a water meter in the first-mentioned case, did not fill with water at much higher speed. But the supply pipe in that case was 1½ inch in diameter, by reason of a decision of the Waterworks Board of Bristol; while in the second case the diameter was 2¼ inches, or considerably more than twice the sectional area. This accounts for the differing results in the two cases, and the consequent very different curves, the engines being exactly the same in every other respect, the length of stroke being 9 inches, and the diameter of the rams 3½ inches.

EXPERIMENTS WITH RAMSBOTTOM WATER MOTOR.

Water motor at Camp's, Bristol, D.HP.=0.4.. ..	Revolutions.	15	18	20	24	27	28
	Pressure.. ..	60	50	45	40	34	30
	Foot lbs....	12,257	12,728	9,428	7,512	5,476	5,280
Water motor at Inst. C. E., London, D.HP. = 0.8.....	Revolutions.	25	50	42	48	55	
	Pressure....	43	40	35	30	25	
	Foot lbs....	21,214	23,570	26,400	25,646	24,420	
Water motor at Inst. C. E., London, D.HP. = 0.8.....	Revolutions.	56	58	60	63	66	
	Pressure.. ..	24	24	23	23	22	
	Foot lbs....	23,084	20,050	18,856	15,840	12,446	

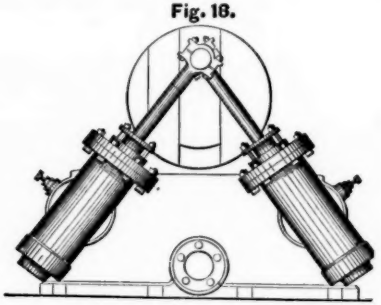
The curves drawn from this table show revolutions as abscissæ and work in foot-pounds per minute as ordinates. The best results obtained in the first case were at the cost of about 2*s.* 10*d.* per HP. per hour; in the second case, at the cost of about 2*s.* 4½*d.* per HP. per hour. These figures were calculated from the greatest work produced, which corresponded to about the highest efficiency; taking the prices charged for water to Mr. Camp at 1*s.* 2*d.* per 1,000 gallons, and to The Institution of Civil Engineers at 1*s.* per 1,000 gallons. Of course the cost for water is much less than this in some towns, being, according to Mr. Hastie, in Glasgow, 4*d.* per 1,000 gallons, at a pressure of 50 pounds per square inch, and in Greenock, 5*d.* per 1,000 gallons, at 120 pounds per square inch; but still the prices, as compared with the cost of a gas engine at 1*d.* per HP. per hour, are high, and in the case of the some engines of a different kind driving the bellows of a large organ in Bristol, the rate is still higher. There is a considerable difference, however, between 5*d.* for 1,000 gallons at 120 pounds pressure and 1*s.* 2*d.* for the same quantity at 60 pounds, the former being 5.6 times as cheap. In Greenock it is found convenient to use water motors for many purposes, especially for intermittent work, such as hoisting.

An important question, and one that has often been raised, with regard to the use of water for the purpose of developing motive power, is the waste sustained by a varying load; for the non-expansive nature of water causes a full complement to be used at each stroke of the engine, whether the load be great or small. This subject was discussed in the paper of Sir W. Armstrong with regard to cranes, where it is said: "It is far less important to consider economy of fuel in the engine, than simplicity of construction in the cranes."* But the arrangement of cranes referred to was not automatic. In the discussion which fol-

* *Vide* Minutes of Proceedings Inst. C. E., vol. I., p. 78.

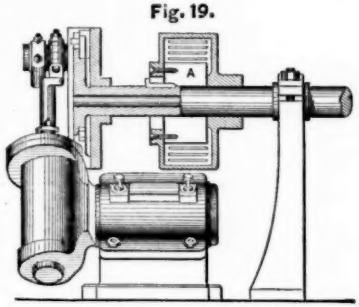
lowed, Mr. Duckam, M. Inst. C. E., showed the considerable loss which might be entailed, and referred (without contradiction) the cause of the objection of Sir W. Armstrong rather to "the necessity of depending upon the intelligence of the workmen, which was far more variable than the crane power." Now, in a recent invention of Mr. Hastie, of Greenock, this difficulty is overcome for water moters by using an automatic appliance of admirable design and simple in principle, thereby meeting the objection above quoted, which of course applied to all water engines. It may be briefly described as a means of varying the quantity of water used by a flexible connection between the power and the resistance, which principle seems capa-

Fig. 18.



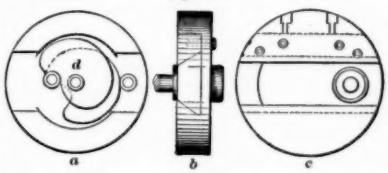
ble of the widest application. From the curves and tables already given it will be seen how much power is lost at the high velocity of the motor which ensues when the supply of water is not regulated to the load. The invention provides for this in the following manner: Fig. 18 shows a front elevation of the two-cylinder form, the cylinders oscillating about their middle point. The piston rods are attached to a crank pin, which slides in or out on the crank plate so as to alter the stroke according to the work to be done. Fig. 19 is a sectional view, showing a drum A, which is attached at one end to a hollow shaft driven by the crank plate, and communicates motion to the solid shaft by means of a spring, of which there are three forms, according to the degree of force transmitted, but which in the present and simplest case is like the spring of a watch. The action is thus: Suppose no load on the machine, then the spring will be uncoiled and the relative positions of the crank plate and solid shaft will be such that the cam shown in *a*, Fig 20, which is driven by the solid shaft, will allow the crank pin to approach near the center of the shaft, and so a small stroke will result, and a consequent small consumption of wa-

Fig. 19.



ter; but if a load be put on the engine, the effect will be transmitted by the solid shaft to the crank plate through the spring, which will be proportionably coiled up, the relative positions changed, and the crank pin driven out by the cam so as to increase the stroke, and consequently the amount of water used to a proportionate extent. In some experiments made by Mr. Kinipple, M. Inst. C. E. engineer to the Greenock Harbor Trustees, 7½ gallons of water were used in a hoist with the chain alone, 10 gallons with 427 pounds, the amount of

Fig. 20.



water increasing with the load, until 22 gallons were registered for raising 1,193 pounds.* Brotherhood's three-cylinder engine has been successfully modified for use as a water-pressure engine, and a description of its action, as well as

* *Vide* Institution of Mechanical Engineers. Proceedings, 1879, p. 487.

drawings of it, are given in a paper by Mr. Tweddell, M. Inst. C. E., read at the Cardiff meeting of the Institution of Mechanical Engineers.*

So far no results from the second of the two sources, viz., water under accumulator pressure, have been given; but taking the average pressure as between 700 pounds and 800 pounds per square inch, and the charge when sold between 3*s.* and 4*s.* per 1,000 gallons, it is evidently far more economical. This question has been so fully discussed by Mr. Robinson in his paper, and the prices of water power from the principal dock systems so completely stated, that only the average cost need be quoted, being 1.26*d.* per 100 foot tons of work, taking 80 per cent. as the efficiency of water. This corresponds to about 1.14*d.* per hour per HP., but of course the efficiency of 80 per cent. could only be obtained for large motors, and would certainly not be much more than half this for small motors; but even this compares favorably with the use of water from the town mains. It is in the use of high-pressure water for varying loads that an automatically regulating engine, such as the one above described, is found to be economical; and this at such rates as 4*s.* per 1,000 gallons, as charged by the Hull Water-Power Company, is at once evident.

ELECTRICITY.

Although the precise nature of electricity is not yet determined, it is known to be a form of energy, and many of the laws which govern its application to the production and transmission of power are understood. Although it cannot be said to be at present to any extent thus practically applied in this country, yet in France its use for the latter purpose is already an undoubted commercial success, and there is every probability that its universal adoption, under certain conditions, is only a matter of time. Therefore it is highly important to compare it with the other agents, the word "agent" in this case not being taken to imply anything material. In order to do this, however, a rather different treatment of the subject will be necessary to that previously adopted, as the machines which may be used, or which are at present used for other purposes, will not be described, but an attempt will be made to present a concise view of the conditions under which electricity must be employed, and of the experimental results recently published, so that the above comparison may be made.

The original method of obtaining an electric current for the performance of work is analogous to the generation of steam in a boiler, fuel being used in both cases; but the energy represented by zinc, which is the substance commonly so employed, is only about $\frac{1}{10}$ of that which an equal weight of coal would produce. As the cost of zinc is about £25 per ton, and of coal only about 10*s.*, the energy obtained from the former is about five hundred times as expensive as from the latter. However, as the efficiency of a small steam engine would be, perhaps, at the best $\frac{1}{10}$ that of a small electric engine, though often nearer $\frac{1}{20}$, the final cost of the work performed would be from fifty to twenty-five times as great.

These figures suffice to show why this method of producing electricity has been abandoned where power is required, and unless some cheaper substance than zinc can be obtained for the purpose, it is never likely to be re-adopted. Nevertheless, ever since the discovery of Oersted (1820), which led to the manufacture of the first electro-magnetic motor, there has been a continual production of such machines, though no attempts to apply them on a large scale have been made since the experiments of Jacobi on the Neva in 1838, whose engine developed about $\frac{3}{4}$ HP. Yet, for many small purposes, they have been adopted, especially in France, for working ruling machines, sewing machines, &c.; but it is a significant fact that the electric pen, in which an engine is actually present, though for a purpose requiring a minimum force, is about their only present use as motive power, even the manufacture of the latest and very efficient Howe electric machine, invented to drive sewing machines and developing about $\frac{1}{6}$ HP., having been now given up.

There is another mode of producing an electric current, viz., by the expenditure of energy from any available source, such as steam or water power, on a magneto or dynamo-electro machine. The

* *Ibid.*, 1874, p. 173.

current so produced is identical in nature with that from a battery, but very different in cost—and upon this point turns the whole question of its possible introduction, for these are practically the only two methods of generating electricity. The latter would obviously only be used for the purpose under consideration, when the steam or water power producing it could not be directly applied, that is could not be obtained on the spot where the application of their energy was needed. This, therefore, reduces the question to the discussion of the efficiency of the transforming apparatus used; and upon the result, that is, upon the percentage of the useful work obtained of that given out by the prime mover, the use of electricity as a transmitter of power depends. In order to do this in a lucid manner the two actions will be discussed separately.

(1) The efficiency of the generator of electricity, giving the loss of power in the production of the current.

(2) The efficiency of the machine which re-transforms electricity into work.

Of course the resultant efficiency is the product of the two; but though, as is often the case, the two machines may be identical in construction, yet the efficiencies may not be the same, since the conditions under which they are respectively used are not identical; that is to say, the efficiencies of the operations are different.

(1.) The first has been made the subject of direct experiment by Dr. Hopkinson, Assoc. M. Inst. C.E., and others. In a paper read before the Institution of Mechanical Engineers by the former,* the results show an efficiency of $\frac{9}{10}$, exclusive of friction; and from the whole set of experiments Dr. Hopkinson deduces a mean total loss of 12 per cent. and of 13.8 per cent. respectively in producing the current; that is, the useful work represented by it is from 86-2 to 88 per cent. of the work applied to produce it. He quotes the results by Mr. Schwendler, M. Inst. C.E., and Mr. Trowbridge, the former obtaining 88 per cent., the latter 76 per cent. All these experiments were made with the machine of Siemens, which undoubtedly gives as high a result as any, and perhaps higher than some machines; but the fact remains, that a return may be obtained which, in connection with the comparison already made between the cost of boiler and battery power, renders the former, as applied in this way, immensely superior to the latter, and proves the loss in producing electricity to be less than in bringing either water or compressed air to a similar state of stored-up energy.

(2.) But the next point is to examine the further loss, viz., in turning the current so produced into work; and this is by no means so easily determined, nor does it yet appear to be a settled question. An electric current may drive either an electro-magnetic engine, or a magneto- or dynamo-electric machine, and the result is theoretically the same. The principle by which motion is caused is the attraction of two pieces, one fixed and the other movable, which may be either one or both temporary magnets, and with this effect: as long as the driven machine is at rest, the full force of the current is expended in overcoming the resistance of the circuit, but immediately upon the load being so reduced that a slow motion is the result, the needle of a galvanometer placed in the circuit will be deflected, showing a diminution of current strength. This is caused by the return current, which it is obvious—at any rate with a magneto or dynamo machine—must be produced immediately it begins to rotate, as it may be supposed to generate an independent current, opposing the original one. Now, the expenditure of energy in the first machine—or the consumption of zinc, whichever it may be, as either may be supposed to be producing the current—is thereby reduced; and this reduction will continue as the speed of the driven machine increases, the needle of the galvanometer showing all the while a fall in current strength. The load on that machine must be of course correspondingly reduced, and the theoretical limit is easily seen to be that point where there is no load at all upon it, the return current equal in strength to the original one, and therefore no current passing, and the velocity of the second machine equal to that of the first, and therefore driving it with equal force to that with which it is driven by it; or if a battery be used, the velocity of the driven machine would

* *Vide* Institution of Mechanical Engineers. Proceedings, April, 1879, p. 238.

depend in a definite way on the battery, producing an equal and similar effect. These conditions it is of course impossible to realize, for, as it is evident that then no work is being done by the source, the friction of the driven machine in practice would prevent this limit being attained. But it is possible to conceive the friction being so reduced that the limit may be closely approached; although as the load is reduced, the useful work done will grow less, and will bear a decreasing proportion to the work wasted in friction. It becomes a most important point to consider the extent to which this can practically be carried—that is, what is the load and corresponding speed giving the highest efficiency?—and is, in fact, an answer to the question as to the amount of work reclaimable from the electric current. In the first place, it must be noticed that the work done at the two limits, viz,, when at rest, and when no current is passing and the machine has its maximum velocity, is zero; and it can be proved in several ways that, as might be anticipated, the greatest amount of work in a given time is realized half-way between these limits. In fact, when the return current is just equal to the forward one, then the efficiency is $\frac{1}{2}$, or the work reclaimed is 50 per cent. This fact was stated in a paper read before the Institution * by Dr. P. Higgs and Mr. R. Brittle, Assoc. MM. Inst. C.E.; in which it was also said that, "supposing two equal machines arranged for the transmission of power, the amount of work reclaimable from the second machine will be 50 per cent. of that employed upon the first, and the number of revolutions of the armature of the second machine corresponding to the maximum of work reclaimed will be half the number made by the first." Experiments were made with a steam engine as prime mover, which showed in one case as much as 49 per cent. of returned energy, at which point the number of revolutions, as nearly stated above, was 1,400 for the driving machine, and 691 for the driven; in other cases the maximum percentage of work returned also corresponded nearly to these conditions, and curves were constructed showing the maximum percentage of work as ordinates, and the revolutions as abscissæ. If, however, 12 per cent. of the work be lost in obtaining the current, then, according to the above theory, only 44 per cent., which is half the remainder, is the amount of work finally reclaimable. Work reclaimed was measured by a dynamometer, which does not register the work done against the friction of the second machine; and this, taken in conjunction with the significant shape of the curves, which all show a more gradual slope as the revolutions increase, after the highest ordinate, and when the ratio of work lost in friction is also increasing, may put the point of maximum efficiency beyond that where the revolutions of the second machine are one-half those of the first, and nearer the point suggested by Dr. Siemens, viz., two-thirds of this. This important question was discussed by Professor W. E. Ayrton, Assoc. M. Inst. C.E., in a discourse delivered to the working men of Sheffield, at a meeting of the British Association for the Advancement of Science in 1879, on "Electricity as a Motive Power." He considers that, by obtaining a high speed with the first machine, and also with the second running with a light load, "the combined efficiency of the arrangement can be made to closely approach the square of 0.86, and not merely one-half, as commonly supposed." * The high speed being necessary to develop a reasonable amount of work in a given time with a light load, the above conclusion really means that the only work lost by the transformation of the current into work need only be just the same as in the production of the current. This being possible, even in theory, would enable it to be predicted that the 49 per cent. already referred to could be considerably increased by improved mechanical construction.† Some experiments by Professor W. C. Unwin, M. Inst. C.E., the drawings and data of which he has kindly placed at the disposal of the author for publication, seem to have a decided bearing on the subject, as they appear to indicate that the theory which requires a light load, in order to obtain a high efficiency, is modified in an important manner by the friction of the

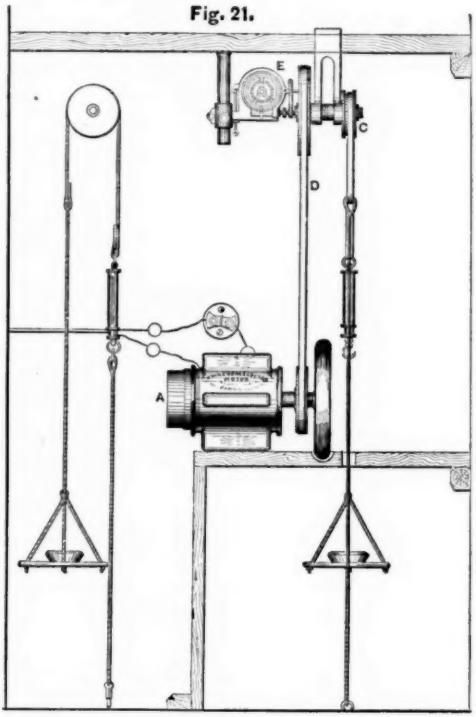
* *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 36.

* *Vide* "The Electrician," vol. iii., p. 191.

† Since the foregoing was written, Dr. Siemens has stated in a lecture at the Royal Institution, that 60 per cent. had been obtained.

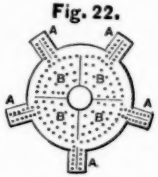
machine itself. The current was obtained from a battery, but the conclusions as to the driven machine seem in no way altered. Fig. 21 is a general view of the

Fig. 21.



arrangement adopted; A is a Howe electric motor, of which Fig. 22 is a sectional sketch showing its general design. It consists of a revolving axis, on which

Fig. 22.



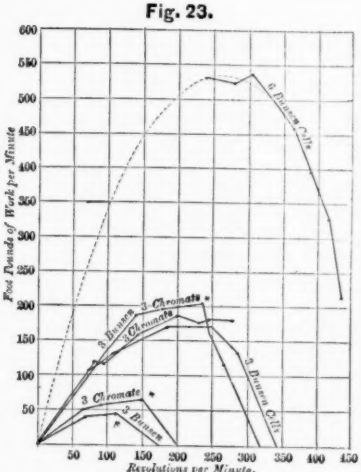
are four electro magnets, BBBB, and which by means of five fixed electro magnets, AAAAA, receives twenty attractions in a revolution. The motor drives a brake wheel, C, by means of a band, D, and also an apparatus, E, for recording the number of revolutions. The brake designed by Professor Unwin, although it appears to have been previously used by Mr. Bramwell, is a most convenient one for small powers, and merely consists of a band passing over C, having a Salter balance on one side, and a scale pan on the other, a side view of this being shown in the figure to the left. Then

P = Force in pounds on brake-rim = pull in balance − weight of and in pan.
V = speed of effective pulley-rim in feet per minute.
P × V = foot pounds per minute.

The time of 100 revolutions was taken by a chronograph in fifths of seconds, and a table is given of the results of six series of experiments of batteries of various kinds and powers. In the three

marked * (Fig. 23) the batteries did not work properly; still the results are given with the others as leading to the same conclusion. From the tables the experimenter constructed the curves shown in Fig. 23, which have for ordinates the

Fig. 23.



Experiments by Prof'r W. C. Unwin.
*In the three cases marked * the batteries did not work properly.*

actual work done in foot-pounds per minute, and for abscissæ the number of revolutions per minute.

Now, according to theory, if there were no friction in the machine, the work should vanish for a number of revolutions just double that at which the work was greatest; that is to say, the ordinate should become zero at a distance from the origin just twice that at which it is a maximum; but in every case this, as would be expected, takes place at a point not only less, but very considerably less, than twice this distance, which means, that at the higher velocities the friction due to the machine itself (assuming the friction due to the load to vary with the load) bears a considerably increasing proportion to the useful work done, and finally causes the latter to vanish, so as to affect in an important way the theoretical efficiency. Assuming the attractions to act so that their influence on the friction is balanced, and the effective circumference of the pulley to be 1 foot, then an expression similar in form to the following will obtain;

If W_1 = load,
W_2 = load due to machine itself,
n = number of revolutions per minute,
μ = some multiplier for friction,

then $n\,[\,W_1 + \mu(W_1 + W_2)\,]$ = work done per minute.

Now, as n is increased, W_1 must be diminished, and finally when W_1 vanishes and n becomes N,

$$N\,\mu\,W_2 = \text{work done};$$

which may be considerable, but is all wasted in friction, this quantity being most important in the question of the possible highest efficiency.

Referring to the curve with six Bunsen cells, the maximum useful work is seen to correspond to 300 revolutions. Now the reading of the galvanometer, which was taken for each experiment, when properly reduced, shows a reduction in current of nearly one-half, thus proving this to be nearly the position of maximum total work; and accordingly, by theory, the efficiency should be also nearly one-half; but assuming 12 per cent. of the work to be lost, as already explained, in obtaining the current, the greatest return of work would be one-half of 88 per cent., or 44 per cent. Now the efficiency would approach 88 per cent. as the revolutions approached 600, but the useful work vanishing at 430, the highest possible efficiency could not exceed $\frac{88 \times 430}{600} = 63$ per cent. But the effect of friction is such that in the present case anything like this is quite unattainable.

The foregoing reasoning cannot pretend to do more than point to the practical bearing that the friction due to the weight of the motor, and its connection, by bands or otherwise, with the work to be done, has upon the efficiency at high velocities, showing that for small powers it is likely to be nearer 50 per cent. than 80 per cent. Messrs. Higgs and Brittle failed to obtain more than 49 per cent., their mean result being 44⅓ per cent. There is a further point to be noticed in connection with the effect of reducing the scale of operations, viz., that with six Bunsen cells, the best results were nearly three times as great as the best results with three, instead of twice, given by

applying Ohm's law; and again, that the number of revolutions for which the useful work was a maximum, and also the number for which it became zero, was less as the battery power decreased, showing that the ratio of loss by the friction of the machine increased with lighter loads and higher speeds.

Still it may be assumed that an efficiency of 50 per cent. may be expected, even on a small scale of application, and this compares favorably with that obtained with other agents. For instance, it is greater than with compressed air, and, under the conditions now considered, than with water; whilst the necessary use of pipes, respectively air or water tight, is certainly more expensive than the use of wires, and in point of convenience also the advantage is greatly on the side of the latter; so that it is probable that the use of electricity will, before long, be applied for many purposes to distribute power and to take the place of the other agents, and even of lines of shafting.

Section III.

In the foregoing section the efficiency of each agent has been stated, as far as possible in terms of the fuel used, but this is only one factor in the question of their relative economy, which includes:

- First cost.....
  - Cost of agent and its efficiency.
  - Cost of attendance, repairs, etc.
- Expense of working
  - Outlay on apparatus, taken in connection with probable durability.

Now, in the present state of small motors, which is not a settled one, the cost of apparatus for some agents, such as gas or electricity, has, it is to be hoped, by no means reached a minimum; while for others, steam, water, and hot air, competition has brought prices to a point below which they cannot be much reduced. Moreover, the question of durability and repairs is with some of them difficult to settle. Again, the same agent may have very varying efficiencies in different motors; while, lastly, an examination of the price lists will show how different are the prices quoted by various makers for the same kind of engines and of the same nominal power. This latter discrepancy partly arises from the present unscientific procedure of defining "nominal" apart from "actual" HP., the evils arising from which would be considerably modified if the pressure, number of revolutions, and the actual power were to be advertised as well as the price, as done by Mr. Brotherhood and others; this would enable the purchaser to judge for himself, and thereby avoid the anomalous varieties in advertised power which visitors to agricultural shows must have noticed in connection with some small motors, and which must be quite inexplicable to the uninitiated. Variation in quality and workmanship has also, of course, a good deal to do with the difference alluded to. For the foregoing reasons it seems impossible to give a tabulated, or even concise, comparison of the agents, as far as their relative cost and efficiency is concerned: but this is, after all, not so important on a small scale as on a large one, the differences not being so great as to make this, in the majority of cases, the predominant one, which is more often rather one of suitability, and which can only be discussed by considering the objects for which the power is required, many of which have been already incidentally mentioned, and which may require either constant or intermittent use, and may give security, regularity, cleanliness, or compactness more or less importance. Therefore, as stated at the commencement of the paper, it seems most satisfactory to discuss their relative advantages in connection with the purposes to which they are applied. In order to do this it must be remembered that the great increase in the number of small motors is the natural result of the progress of applied science, by which the substitution of machinery for manual operations tends to bring about a displacement of muscular effort by the application of natural sources of power; but it is important to observe that this is taking place under two different conditions.

(1.) Where an extensive source of power is not directly available, as in small isolated factories, in shops, private houses or in the country.

(2.) Where—as on board a steamship, or a large factory, or in a system of docks—there is already a supply of the

working agent on a large scale, often for driving a prime mover of considerable size, which supply may in many ways be turned to use by small motors, for superseding manual labor.

These conditions may materially modify the conclusions as to the choice of a small motor. For instance, the steam engine which is less economical than the others was shown to be so, chiefly on account of the small boiler, but may give a very different result if supplied with steam from a large and efficient one, where, in addition, one attendant only is required, for perhaps a score of engines instead of for the single small one; so that these two cases will be treated separately.

(1.) A special aspect of the former has been considered in the pamphlet by Peter Hell, already referred to, in which the writer earnestly advocates the increased application of small motive power, now to be obtained at moderate cost, for the revival of the domestic industries of Germany, which have suffered so severely from the introduction of large factories with powerful engines. He takes as a particular example the case of the weaver, who might, he considers, be restored to his former position of comfort, by the use of a small cheap motor, and "might be himself able to employ his supposed deadly enemy, the mechanical loom."* He also deals briefly with the use of small motors for agricultural purposes. This accounts for the conclusion arrived at by him, viz.: that the only suitable agents are gas and hot air; his opinion being that the motors of Otto and Langen, for the former, and Lehmann's "closed" and the Hock "open," for the latter, are the most efficient. For what has been shown, there is no doubt that the conclusion, as far as the agents themselves go, is, under the special circumstances, a sound one. For small manufacturers, for private individuals, in shops, &c., and for the many subsidiary industries carried on in the large towns of this country, the recent silent gas motors have supplied a long-felt want, this being abundantly testified by their remarkable sale. Gas is immediately accessible, no special attendance is required, the engines work in the same room with the other machinery, performing the most delicate work; they are clean and noiseless, and always ready at a moment's notice to commence work. Some of these advantages pertain to the use of hot air, and one is certainly common to both, viz.: the obviation of all danger of explosion, a consideration of great importance. But the great disadvantage of hot air is the limited power which small engines develop; though for light purposes, where gas cannot be obtained, the hot-air engine of Rider or Lehmann forms an efficient substitute. In analyzing the list published by Messrs. Crossley Brothers, of the silent gas engines sold by them during the two years or so since their introduction, 40 per cent. of the $3\frac{1}{2}$ H.P. went to small manufacturers, including boot and shoe manufacturers (of which six went to Bristol alone), jewelers, turners, and for sawing, weaving, clock making, spring making, and aerated water machinery, and for many like purposes; while 31 per cent. of the 1 HP. were supplied for printing and lithographing machinery, for which, especially the latter, the absence of dust and dirt is a desideratum. For the foregoing purposes and for lifts for hotels, infirmaries, warehouses, &c., the slight attendance required with gas or hot air is a great advantage, a small steam engine being really a troublesome thing, the regulation of the water to the boiler, &c., requiring almost the full attention of one man. Water from the mains may, however, be conveniently applied to all the purposes mentioned where, as in Glasgow or in Greenock, it is cheap and under considerable pressure. It possesses all the advantages already claimed for gas or hot air, with the additional one of absolute immunity from the danger of causing a conflagration. Mr. Hastie, of Greenock, in a letter to the author, states that "the purposes to which water motors are applied in Glasgow, are as follows: Hoists, very extensively; by carpenters, for working circular saws; by bookbinders, bakers, hairdressers, at churches for organ blowing, in public institutions for washing and wringing machines, and also for chaff cutting and meat mincing." He goes on to say that the expense for water is in some cases very little; in one case, to a printer, it was 9s. per quarter, and in many cases in Greenock the minimum rate charged

* "Klein-Kraft-Maschinen," p. 9.

by the water company, viz.: 20*s.* per quarter is not exceeded. However, these liberal terms, unfortunately, cannot be obtained in the majority of large towns, and then gas is generally the best agent.

For private houses, laboratories and shops, where the power required is often little more than nominal, and its use intermittent, the small first cost of a water engine (the Ramsbottom being about £80), in conjunction with the other advantages, may be often sufficient to more than counterbalance the high rate of the water from the mains; but for such purposes, especially when a water meter is used, the custom of charging a high minimum rate, often considerably exceeding the actual cost of the water used, stands in the way of its adoption. In one case in Bristol a minimum rate of £20 per annum is charged for three pairs of small engines, which are only required for six or eight hours per week. In the country a small fall of water from a stream may often be used for pumping purposes, when a water wheel or small turbine affords a very efficient method of utilizing it.

One application of gas not yet mentioned is that to the electric light. It is found for some purposes more economical to use gas indirectly to produce illumination, rather than to use it directly. From the paper of Mr. Alexander Siemens, read April 2d, before the Society of Telegraph Engineers,* it appears that a saving of from 47 per cent. to 87 per cent. is thus obtained. In the British Museum a saving of 60 per cent. is effected by the substitution of electric light for gas; but in this case the motor is a steam engine, and it is necessary to keep the fires alight all day in order to be ready at a moment's notice, the cost of attendance being 1.2 of the light itself. In the Albert Hall the saving is, in the same way, 66 per cent.; so that, whilst the absolute cost of steam is perhaps less than that of gas, its convenience and readiness of application are also less. Where gas is not available, then steam, supplied generally by portable engines, must be used.

For agricultural purposes gas is out of the question; and where water power is inaccessible, as is generally the case in this country, either steam or hot air must be resorted to. For purposes requiring much power—as thrashing, plowing, &c.—steam must hold its own; but for light work, such as fodder cutting and pumping, the hot-air engine is beyond all doubt the most suitable, that of Rider, which is semi-portable, and requires no skilled attendant, being often used.

For purposes where small portable motors are required—as for contractors' work, for cranks, for rather large pumps—small vertical or horizontal steam engines and boilers will no doubt always be used, from the fact of the considerable power developed by them in comparison with their weight and size.

(2.) In the second division, where a source of power is already at hand, the circumstances are altered. On a steamship or in a large factory, where there is an abundant supply of steam, produced economically, because on a large scale, no agent can compare with it. In the first instance, viz., on a steam ship, where the area of distribution is limited, this is especially the case; and for steering, hoisting the cargo and anchor, turning the capstans and windlass; for ventilating, pumping, &c., small auxiliary steam engines are invariably used, when these duties are not performed by hand. In the second case, it is often found to be more desirable to use auxiliary engines, for driving machines—as for instance the centrifugal machine in a sugar house, or the punching and shearing machines of a shipbuilding yard, both these being formerly driven by shafting; but to the former small Brotherhood three cylinder engines are often now directly applied, and the fluctuation in speed on the main engine, caused by the intermittent use of the machine, is thus avoided, and a much smaller one required.

Again, in a system of docks where an accumulator if used for supplying water under great pressure for large cranes, it is more convenient to use small high-pressure water engines than any others. For instance, in connection with the Cumberland basin, Bristol, there are twenty-three sets of small oscillating water engines, supplied by Sir W. Armstrong, there being sixty-six small cylinders used, averaging not more than 2 or 3 inches in diameter; these are applied to move the bridges, gates and capstans

* *Vide* "Journal of the Society of Telegraph Engineers." Vol. IX., p. 89.

connected with two docks, and are easily and rapidly put into operation. During the last two winters of severe frost, not a single accident has happened through the bursting of pipes, and the suitability of water for this purpose is undoubted, In a large system of warehouses, such as at Birkenhead, water power is certainly to be preferred to any which necessitates the introduction of fire or light, and at Hull the system has received considerable development.

The conclusions are, briefly, that gas is generally to be preferred as an agent for small manufacturing operations—for hoists in buildings, &c.; but water and hot air both have decided advantages—the former, when obtainable at a low rate, the latter for light purposes, when neither of the others are available. For private houses, shops, &c., water, even at a dear rate, may often be applied. The proper applications of steam have been indicated, and though likely to be more and more superseded by the other agents in the foregoing cases, particularly by gas, yet there is a large field in which small steam engines must continue to hold their own.

In conclusion, the author wishes to record his thanks to Professor Unwin, for the data and suggestions supplied by him; to Dr. Main, Professor of Mathematics and Engineering, University College, Bristol, and to Messrs. C. D. Selman and A. W. Metcalfe, students; as well as to those gentlemen who have allowed him to test their engines, or have supplied him with information.

THE FLOW OF GASES THROUGH TUBES.

GENERAL AND PRACTICAL PROBLEMS.

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THE great demand of late years for compressed air transmitted long distances, through tubes, has created a necessity for a proper basis of calculation for the use of engineers in practice. The most trustworthy means yet produced appears to be a table obtained from experiments made under the Italian Government about forty years ago. And, indeed, this table appears to have failed of application in many cases for want of publicity. The answers to some great questions have been so delayed, for want of ready means for calculation, as perhaps to have caused the failure of some important works.

Formulas have, however, existed which, though not fully correct, would have given results not far from the truth. It is, perhaps, forty years, since European engineers accepted the doctrine that a formula, suitably expressing the conditions of flow of one fluid in a tube, is applicable to all others. A statement of such doctrine was made in a supplementary part of an important French work on hydraulics, published nearly forty years ago, by M. D'Aubuisson.

This principle may now be unhesitatingly accepted as truth for all cases where the conditions of the fluid, as regards density, remain the same. That is to say, when the density remains sensibly constant, as in water, and as in illuminating gas, very nearly; because the absolute pressure remains one atmosphere within about one per cent. the ordinary formulas of hydraulics will apply. When the density varies according to any certain law expressed as a function of distance along the pipe, another set of formulas will apply, and for all fluids under this law. These formulas will differ from those of hydraulics. Again another law of density will give another set of formulas, &c.

The peculiarities just stated respecting laws of density are common to flow of gases through orifices as well. But for this there seems to be but two cases: 1st. When the change of pressure is so slight that the change of density may be neglected; and, 2d. When the change of pressure is so great that change of density is considerable, and the flow is to be considered as adiabatic. For the

first the formulas of hydraulics for discharge through orifices will apply; while, for the second, they will not. But formulas for adiabatic flow have already been worked out, and are to be found in numerous works on heat.

But for pipes there may be an indefinite number of laws of density, among which we find three prominent special cases: I. Density constant. II. Density varying as for the adiabatic flow. III. Density varying as for constant temperature, and for assumed laws of varying temperature.

I.—This has already been referred to as that where the ordinary formulas of hydraulics for flow through pipes are applicable. These formulas, however, are usually stated with reference to head h, the same being the elevation of the free surface of water at the source, above the point where the water becomes free at the discharge. If the exit is submerged in a tank, then the level of the lower free surface is the lower point of head. This head is sometimes called dynamic head, because it measures that head to which the motion in the pipe is due. This head may be stated in terms of the statical pressure due to the difference of level and density of the fluid. It is equal to the height of a column of fluid with a unit's area of base, and with a density equal that of the fluid flowing, the weight of which is equal to the above statical pressure. That is, let p = the statical pressure and δ the density of the fluid flowing through the orifice or pipe. Then

$$h=\frac{p}{\delta} \quad . \quad . \quad . \quad (1)$$

But this pressure p may be a difference of two pressures. Thus suppose a horizontal plane situated at a distance below the free surface, both at the source and at the exit from pipe. Let p_1 be the weight of a column of the fluid of unit's area, supposed standing on this plane and reaching to the upper level. Similarly let p_2 be the weight of a column reaching to the lower level; then

$$p_1-p_2=p,$$

and hence

$$h=\frac{p_1-p_2}{\delta} \quad . \quad . \quad . \quad (2)$$

In gaseous fluids these pressures are more readily observed than h. For instance, suppose a receiver containing compressed air at 50 lbs. pressure per square inch, or 7,200 lbs. per square foot. Let this discharge by a pipe into another at 7,100 lbs. per square foot. The specific density of air at this pressure or weight per cubic foot is, say 0.32 lbs. Then

$$h=\frac{p_1-p_2}{\delta}=\frac{7200-7100}{0.32}=312.5 \text{ ft.}$$

In this example the fall of pressure, also of density, is a trifle over one per cent., and if that can be regarded as not giving cause for a change of final result which will be noticeable, this value of h may be introduced into the hydraulic formulas for computing velocity of flow of air for this case. The velocity of flow of the air will here be the same as that of water through the same pipe under a head of the same 312.5 ft.

The same expression for h is also applicable to the formulas for flow through orifices under small changes of pressure. Thus,

$$v=u\sqrt{2gh}=u\sqrt{2g\frac{p_1-p_2}{\delta}} \quad . \quad . \quad . \quad (3)$$

u being the coefficient of velocity. The density, δ, should be taken as that due to a pressure midway between P_1 and P_2, or to the pressure

$$\frac{p_1+p_2}{2}=p'.$$

Let $\tau'=461.2+t'$, be the absolute temperature of the flowing gas. Then according to the M. and G. laws

$$\frac{p'}{\delta\tau'}=\frac{p_0}{\delta_0\tau_0}$$

the quantities in the second member being taken at the melting point of ice.

Then

$$h=\frac{p_1-p_2}{\delta}=\frac{p_1-p_2}{p'}\cdot\frac{p_0\tau'}{\delta_0\tau_0}$$

$$=2\frac{p_0\tau'}{\delta_0\tau_0}\cdot\frac{p_1-p_2}{p_1+p_2} \quad . \quad . \quad . \quad (4)$$

The object of this modification of the expression is to facilitate the necessary account to be taken of the density, the values of the quantities at ice-melting temperature being usually found in tables.

To obtain a rational expression for the flow of gases in pipes we have for the outset the well-known relation

$$R=f\delta A\frac{v^2}{2g}, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where R is the resistance to fluid friction of a fluid whose specific density is d, moving with a velocity v, along a surface of the extent A; f being the coefficient of fluid friction, and g the acceleration of gravity. In applying this to find the resistance to the movement of a fluid through a pipe, A is to be taken = the internal surface of the pipe in contact with the moving fluid. Hence $A=sl$, where s=perimeter of cross section and l=length of pipe. Also R=the pressure which has to be exerted against the end of the column of fluid in the pipe to force the tube-full along, making $R=(p_1-p_2)a$, where a=the sectional area of pipe. Hence

$$R=(p_1-p_2)a=f\delta A\frac{v^2}{2g}, f=\delta sl\frac{v^2}{2g}$$

or

$$\frac{v^2}{2g}=\frac{a}{fsl}\cdot\frac{p_1-p_2}{\delta}=\frac{ah'}{fsl} \quad . \quad . \quad . \quad (6)$$

where v=velocity of fluid in the pipe, a=area of cross section, s=perimeter of cross section, and l=length.

This expression evidently takes account only of the resistance to fluid friction between the fluid in the pipe and the inside surface of pipe. In very long pipes this is the chief resistance, but in short ones the acceleration at the entrance to pipe has to be taken into account, that is, the work necessarily performed to produce v, if w = the weight of the fluid entering the pipe per second. This, multiplied by the height, or head, h, gives a quantity of work per second,

$$wh''=FS=\tfrac{1}{2}MV^2=\frac{W}{2g}V^2$$

or

$$h''=\frac{V^2}{2g} \quad . \quad . \quad . \quad . \quad (7)$$

where the relation $FS=\frac{1}{2}MV^2$ is a fundamental formula in mechanics applicable to the present case as expressing the relation between the force F, or weight W; space S, or height h; and resulting velocity V of the mass M of the weight W of fluid, which is moved per sec. from a condition of rest in the reservoir, into the pipe where it has the velocity V. But this velocity is the theoretic, the actual velocity v, being the theoretic, multiplied by the coefficient of velocity u, found by experiment. Hence actual velocity

$$=uV=u\sqrt{2gh''}=v \quad . \quad . \quad . \quad (8)$$

The heads appearing in (6) and (8) are different, one being consumed in overcoming friction, and the other in producing motion. The sum of these should evidently be taken to obtain the whole head for short pipes, where the latter is too great to be overlooked. Adding, we get

$$h'+h''=h=\frac{v^2}{2gu^2}+\frac{fsl}{a}\frac{v^2}{2g}=\left(\frac{1}{u^2}+\frac{fsl}{a}\right)\frac{v^2}{2g}$$

whence

$$\frac{v^2}{2g}=\frac{h}{\frac{1}{u^2}+\frac{fsl}{a}} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

a formula for a pipe, however short or long; when very long the first term in denominator may be neglected, and the equation becomes (6). When the pipe is very short the 2d term becomes inconsiderable and the expression reduces to (8) or (3). In using this equation h is the same as h in eq. (4), by which the proper head is to be found.

This is a general formula for all pipes for the present case, that is to say, pipes of uniform cross section, and for conveying fluids of invariable density. It therefore is a general formula for hydraulic pipes, for rivers and canals: for pipes distributing street gas, for air ducts employed in ventilating buildings, for galleries and passageways in ventilating mines, for conveying steam and air at high pressure where the pressure falls but slightly and temperature remains constant. The formula includes all the various hydraulic formulas ever given for pipes and rivers. Paradoxical as this may at first appear, it becomes evident enough when it is noticed that all the discussions of hydraulic formulas for pipes and rivers are, in effect, simply discussions of the coefficient of fluid friction f. These discussions make it appear that f is not absolutely constant, some contending that it varies slightly with velocity, others with the radius of pipe, others with radius and velocity, &c. For instance, according to

Coulomb, $f=a+\frac{b}{v}$.

Weisbach, $f=a+\frac{b}{\sqrt{v}}$.

Darcy & Bazin, $f=a+\frac{b}{r}$.

Eytelwein & Leslie,

$$f=a.$$

Neville, $f=\left\{a+b\left(\frac{f}{v}\right)^{\frac{1}{2}}\right\}^2$.

Gauguillet & Kutter,

$$f=1\div\left(a-\frac{ab}{\sqrt{r}+b}\right)^2.$$

Du Buât,

$$f=1\div\left(\frac{\frac{b}{\sqrt{r}}}{1-cv\sqrt{\frac{f}{r}}\log\left(\frac{r}{v^2f}+e\right)}+\frac{i}{v}\sqrt{\frac{r}{f}}+\frac{j}{v\sqrt{f}}\right)^2$$

from which it might at first appear that f may have almost any value or expression. But in practice it is found to be slightly variable, its extremes being found under extreme conditions, such as very large or small velocities, or of cross sections of current. From this fact it would appear that its expression should be a function of both v and r, as indeed we find it in the last above, and this may explain why this formula of Du Buât, though one of the earliest, is still recognized by some writers as one of the most truthful yet produced. Its complexity interferes with its use in practice, but tables may be computed for f, by aid of which its advantages become available. The constants a or b, &c., in the expressions for f, are not all the same numerically; r being the "mean radius."

A good approximate value is

$f=.005$ or $.006$ ordinarily.

To indicate the application of eq. (9), let it be required to calculate the fall of pressure between the steam chest and steam cylinder of an engine when that fall is not great. The formula (9) does not account for the curves in the passage, the loss of pressure due to bends being determined by a separate and independent calculation. Here the pipe is too short to admit of neglecting the 1st term in the denominator, the value of the coefficient of velocity u being in this case that for an ajutage, and $= .82$. Taking $f=.006$ $2g=64$, and $h=\frac{p_1-p_2}{\delta}$, we have

$$\frac{v^2}{64}=\frac{\frac{p_1-p_2}{\delta}}{\frac{1}{(.82)^2}+.006\frac{sl}{a}}$$

$$p_1-p_2=\frac{\delta v^2}{64}\left(1.487+.006\frac{sl}{a}\right)$$

$$=\frac{\delta v^2}{10700.}\left(248+\frac{sl}{a}\right) \quad . \quad . \quad . \quad (10)$$

for a formula adapted to steam cylinder passages, where $v=V\frac{A}{a}$ = the velocity of the steam as it flows along the passage.

By these formulas p_1-p_2 will be in lbs. per square foot. δ the weight of the flowing steam per cubic ft., l the length of the passage in feet, a the sectional area of the passage in square feet, S the perimeter of the section of passage in feet, V the piston speed of engine in feet per second, and A the sectional area of the steam cylinder in square feet.

As an example to illustrate use of (10) take a piston speed of 300 ft. per minute, or 5 ft. per second = V, A = 1 square ft., $a=\frac{1}{20}$ square ft. $= 1\times 7.2$ inches, $= 7.2$ square inches, $l'=1$ ft., $s=16.4$ inches $=$ 1.367 ft. Take the steam pressure at 75 lbs. per square inch absolute. Then

$\delta=\frac{1}{5.67}=.1764$, $v=100$, and

$P_1-P_2=$ 40.9 lbs. per square ft.
$=0.284$ " " " inch.

The velocity being here 100 ft. per second, the result corroborates the statement of Rankine's work on the steam engine, that this velocity causes no very considerable fall in pressure.

II. For flow adiabatic, or where no heat is transmitted to the gas while flowing, and for great fall in pressure, it will be necessary to adapt a formula to a very short portion of the pipe and take the sum of the effects due to all the

parts of length. Formula (9), neglecting the resistance due to the orifice of entry, becomes

$$\frac{v^2}{2g}\cdot\frac{fsl}{a}=h=\frac{p_1-p_2}{\delta} \quad . \quad . \quad . \quad . \quad (11)$$

Applying this to a very short pipe whose length is dl, we will obtain a small loss of head due to it of $p_1-p_2=dp$, and we have

$$\frac{v^2}{2g}\frac{fs}{a}=dl\frac{dp}{\delta} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

a general differential equation for pipes conducting fluids of varying density. Though δ is to be regarded as a constant for the length dl, it is to vary for greater portions of pipe length according to the assigned law of density. The velocity in the pipe will also differ from point to point, and hence v is a variable. By expressing these variables as functions of l or p, the integration may be performed and the desired formula obtained.

In the present case of adiabatic flow we will have

$$\frac{v}{v_2}=\frac{\delta_2}{\delta}=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad (13)$$

where v_2, δ_2, and p_2 are for velocity, density and pressure at the exit from the pipe considered, while v, δ, and p are for any other point in the pipe. The value of γ for air, and gases nearly perfect, is, according to best authority, $=1.408$.

By (13), (12) becomes

$$\frac{v_2^2}{2g}\left(\frac{p_2}{p}\right)^{\frac{2}{\gamma}}\frac{fs}{a}dl=\left(\frac{p_2}{p}\right)^{\frac{1}{\gamma}}\frac{dp}{\delta_2}$$

or

$$\frac{v_2^2}{2g}\cdot\frac{fs}{a}\cdot dl=\frac{p^{\frac{1}{\gamma}}dp}{\delta_2 p_2^{\frac{1}{\gamma}}}$$

which, for limits o and l and for P_2 and P becomes

$$\frac{v_2^2}{2g}\frac{fs}{a}l=\frac{\gamma}{\gamma+1}\cdot\frac{p_2}{\delta_2}\left\{\left(\frac{p}{p_2}\right)^{\frac{\gamma+1}{\gamma}}-1\right\} \quad . \quad (14)$$

the desired formula in which v_2 is the velocity at the outflowing end of pipe, and p the pressure of the gas at the inflowing end. After integration p, v, and δ, are for quantities just within the orifice of entry.

The fall of pressure from p to p_2 is due to the fluid friction in the pipe. If the pipe is comparatively short, the resistance at the orifice of entry may be too great to overlook. That is, the energy of motion required to give the gas the velocity v, may be as great, or even greater for a short pipe, than the frictional resistance. This resistance at entry is to be treated as a resistance to efflux through an orifice. Formula (3) will not apply here exactly, because now the density is variable. But (13) enables us to express the density as a function of p, thus

$$\frac{\delta_1}{\delta}=\left(\frac{p_1}{p}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad . \quad (15)$$

where δ_1 and p_1 are for density and pressure in the reservoir, while before integration δ and p are for any point before entrance to pipe is fairly gained. Hence, making $p_1-p_2=dp$, eq. (3) may be put under the following form:

$$\frac{v^2}{2gu^2}=\int_p^{p_1}\frac{dp}{\delta}=\frac{p_1^{\frac{1}{\gamma}}}{\delta_1}\int_p^{p_1}\frac{dp}{p^{\frac{1}{\gamma}}}=\frac{\gamma}{\gamma-1}\frac{p_1}{\delta_1}$$

$$\left\{1-\left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad . \quad . \quad (16)$$

But after integration p, v and δ should be considered as in (14) for quantities just inside the entrance to the pipe. If v is found in terms of v_2 it might be used in connection with eq. (14). By aid of (13), we may write

$$\frac{v^2}{2gu^2}=\frac{v_2^2}{2gu^2}\cdot\left(\frac{p^2}{p}\right)^{\frac{2}{\gamma}}=\frac{\gamma}{\gamma-1}\frac{p_1}{\delta_1}$$

$$\left\{1-\left(\frac{p}{p_2}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad . \quad . \quad . \quad . \quad (17)$$

In calculating the velocity v_2, by aid of eqs. (14) and (17), p will always be an unknown quantity, and unfortunately it cannot be eliminated so as to give an equation which is resolvable with reference to v_2. Therefore to find the whole resistance, viz., that due to orifice of entry, and to fluid friction in the pipe, it will be necessary to make a series of trials till we find such a value of p as

will give the same value to v_2 in the two equations. That will be the desired value of the velocity of exit from the pipe, all resistances being considered.

In practice these equations for strictly adiabatic flow cannot be applied to very long pipes, because the flowing gases will acquire same measure of heat. Hence, as the resistance at the orifice of entry becomes greater in comparison with the frictional resistance as the pipe is shortened, it appears that when (14) is to be employed (17) should be also.

III. Let the pipe be considered as so long that an appreciable amount of heat is transferred to the gas while in transit through it, and yet not sufficient to make the flow isothermal. Then some modified value of γ might be used, as lying between 1.408 and 1.

But it may be more convenient to express the temperature as it varies along the length of the pipe as a function of l, or, taking τ for the absolute temperature,

$$\tau = \mathrm{F}(l).$$

In this case, instead of eq. (13), we should write

$$\frac{v}{v_2} = \frac{\delta_2}{\delta} = \frac{\mathrm{P}_2}{\mathrm{P}} \frac{\tau}{\tau_2} = \frac{\mathrm{P}_2}{\mathrm{P}} \frac{\mathrm{F}(l)}{\tau_2} \quad . \quad . \quad . \quad (19)$$

and hence we should have, instead of the equation next following (13), the following, viz:

$$\frac{v_2^2}{2g} \frac{fs}{a} \left(\frac{p_2}{p} \frac{\mathrm{F}(l)}{\tau_2} \right)^2 dl = \frac{p_2}{p} \frac{dp}{\delta_2}$$

or

$$\frac{v_2^2}{2g} \frac{fs}{a} \left(\frac{\mathrm{F}(l)}{\tau_2} \right)^2 dl = \frac{p dp}{p_2 \delta_2} \quad . \quad . \quad . \quad (20)$$

an expression which is integrable when the form of $\mathrm{F}(l)$ is known.

As an example suppose the temperature increases uniformly with the distance along the pipe from the exit up. Then, for τ_2 at exit,

$$\tau = (\tau_2 + ml) = \mathrm{F}(l)$$

l being here variable as representing various lengths of the pipe. If l' is the whole length of pipe, and if τ_1 is the temperature at the entrance to pipe, we have

$$\tau = \tau_2 + \frac{\tau_1 - \tau_2}{l'} l$$

Hence (20) becomes

$$\frac{v_2^2}{2g} \cdot \frac{fs}{a} \left(l + \frac{ml^2}{\tau_2} + \frac{m^2 l^3}{3\tau_2^2} \right) = \frac{p_1^2 - p_2^2}{2\delta_2 p_2} \quad . \quad . \quad (21)$$

But when the flow is strictly isothermal we have $\gamma = 1$ in eq. (14), or $m = o$ in eq. (21), all of which reduce to the eq.

$$\frac{v_2^2}{2g} \frac{fs}{a} l = \frac{p_1^2 - p_2^2}{2\delta_2 p_2} \quad . \quad . \quad . \quad . \quad (22)$$

Should it be desired to take into account the resistance of the orifice of entry in calculations for flow through pipes by any of the latter formulas, it may be done by use of eq. (3) or (17), as whether the fall of pressure is slight or considerable at the entry. In cases where (22) is applicable, however, it will scarcely be found necessary to consider the resistance at entry, because then the pipe will be relatively very long, making that resistance comparatively inappreciable. Eq. (22), indeed, is applicable to the case of conveying compressed air into tunnels as at Hoosac, Mont Cenis, St. Gothard, &c., or as proposed by H. H. Day, in a scheme for compressing air at Niagara Falls, to be used at Buffalo, Rochester, &c. For such extraordinary lengths the resistance at entry would vanish. The flow could then be regarded as strictly isothermal, provided the pipes were at constant temperature throughout, a condition nearly realized by burying the entire line of pipe. Formula (27) has been employed in my lectures to classes for the past 8 or 9 years.

FORMULAS FOR PRACTICE.

In the preceding the leading object has been to state the true relation between the quantities treated. As regards II and III, more convenient forms for application to practice will be considered.

First, we notice that in the use of such quantities as before us, frequent reference to tables of physical constants, &c., is necessary, and these are usually given for the temperature of melting ice. Hence:

Let p_0, δ_0, and τ_0 represent the specific pressure, specific density and absolute temperature for the temperature of melting ice. $\tau_0 = 493.°2$ Fahr.

p_1, δ_1, and τ_1 the same for the gas in the reservoir at the point of departure in the flow.

p, δ, and τ the same just inside the orifice of entry.

p_2, δ_2, and τ_2 the same at the instant of exit.

v, and v_2, the velocity of the stream of gas at the entrance and exit.

a, s, l, sectional area, perimeter of section and length of flowing stream.

The term *specific pressure*, is taken to mean the pressure in units per unit of surface, as lbs. per square ft. *Specific density* is the weight in units per unit of volume, as lbs. per cubic ft.

For gases sensibly perfect, like air, illuminating gas, &c., we have the well-known relation

$$\frac{p_0}{\delta_0 \tau_0} = \frac{p_1}{\delta_1 \tau_1} = \frac{p_2}{\delta_2 \tau_2} = \frac{p}{\delta \tau} \quad . \quad . \quad . \quad (23)$$

$= 53.15$, air; or $= 88$. illuminating gas; for lb. ft. F. units, true for a given gas under all circumstances, whether expanding adiabatically, or in any other manner. But for many cases the three quantities p, δ and τ vary, as, for instance, in the adiabatic condition.

In eq. (14) the density δ_2 is unknown, but as the entire flow is supposed adiabatic, quantities in the reservoir are connected with those at other points according to (13). Hence

$$d_2 = d_1 \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} = \frac{\delta_0 \tau_0}{p_0} \frac{p_1}{\tau_1} \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} \quad . \quad . \quad . \quad (24)$$

δ_1 and p_1 being quantities in the reservoir.

The flow of weight, or weight of gas discharged, is always

$$av\delta = av_1\delta_1 = av_2\delta_2 = w \quad . \quad . \quad . \quad (25)$$

so that the weight can be found for the adiabatic flow, by use of (14), (17), (24), and (25). When the resistance of the orifice of entry is neglected, (17) is an necessary, and p, in (14), becomes p_1.

The second members of (21) and (22) may be put in the following form:

$$\frac{p_1^2 - p_2^2}{2\delta_2 p_2} = \frac{p_0}{\delta_0 \tau_0} \cdot \frac{\tau_2}{2} \frac{(p_1^2 - p_2^2)}{p_2^2} =$$

$$\frac{p_0}{\delta_0 \tau_0} \cdot \frac{\tau_2}{2} \left\{ \left(\frac{p_1}{p_2}\right)^2 - 1 \right\} =$$

$$\frac{p_0}{\delta_0 \tau_0} \tau_2 \frac{(p_1 - p_2)}{p_2^2} \frac{(p_1 + p_2)}{2} =$$

$$\frac{p_0}{\delta_0 \tau_0} \tau_2 p_m \frac{p_1 - p_2}{p_2^2} \quad . \quad . \quad . \quad (26)$$

where p_m = the arithmetical mean of the pressures p_1 and p_2.

For small differences of pressure p_1 and p_2, we have $p_m = p_2$ nearly, and (26) becomes

$$\frac{p_0}{\delta_0 \tau_0} \tau_2 \frac{p_1 - p_2}{p_2} \text{ nearly.}$$

For air the equation (22) for isothermal flow through cylindrical pipes becomes

$$v_2^2 = 284943 \cdot \frac{r}{l} \tau_2 p_m \frac{p_1 - p_2}{p_2^2} \quad . \quad . \quad . \quad (27)$$

r being the radius of the pipe, and the coefficient of friction being taken at

$$f = .006.$$

This equation (27) has been compared with the results of experiment as indicated in the accompanying table, the column of calculated velocities at exit having been obtained by aid of this formula. The comparisons indicate that the coefficient of friction is in some cases less in value than the .006 assumed, notably for the St. Gothard experiments, for which .004 would have given results agreeing more closely. But it is difficult to discover a law relating f with r or v, or both; which will reconcile the discrepancies shown in the table. For instance, compare the Italian experiments with the St. Gothard, for velocities of 15 to 20 ft. and diameter of pipe 7.87. Like velocities and diameters being found in both, it appears that f, stated in terms of v and r, would be the same for both and could not be otherwise. Hence f cannot be stated in terms of v and r alone, so as to satisfy all the experiments.

If f be taken as a function of p, so as to reconcile the two cases above considered, the same will be wrong for making the results of experiment of Henson and calculation agree. The experiments of Henson were made with lead pipe.

If we assume that the St. Gothard experiments are more trustworthy than the others, this would argue a smaller value of f. But from these experiments, all considered, probably no better value of $f = .005$ could be assumed.

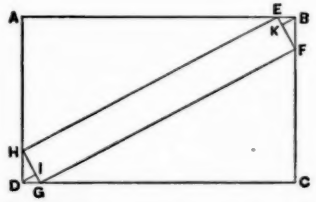
TABLE OF VELOCITIES OF COMPRESSED AIR AT THE EXIT FROM LONG PIPES. OBSERVED AND CALCULATED

Experiments.	Absolute. P_1	Absolute. P_1-P_2	d	l	τ_2	f	Velocity u_2. Calc'd	Velocity u_2. Obs'd	Diff.
	lbs.	lbs.	inches.	ft.	Fahr.				
From experiments made by order of the Italian government, preliminary to use of compressed air in the Mont Cenis Tunnel.	90.	.117	3.937	3281.	520.	.006	3.12	3.28	− .16
	—	.516	—	—	—	—	6.58	6.56	+ .02
	—	1.218	—	—	—	—	10.18	9.84	+ .34
	—	2.125	—	—	—	—	13.54	13.12	+ .42
	—	3.289	—	—	—	—	17.01	16.40	+ .61
	—	4.586	—	—	—	—	20.29	19.68	+ .61
	90.	.062	7.875	3281.	520.	.006	3.22	3.28	− .06
	—	.258	—	—	—	—	6.55	6.56	− .01
	—	.609	—	—	—	—	10.12	9.84	+ .28
	—	1.062	—	—	—	—	13.41	13.12	+ .29
	—	1.656	—	—	—	—	16.64	16.40	+ .24
	—	2.304	—	—	—	—	19.96	19.68	+ .28
	90.	.039	13.75	3281.	520	.006	3.37	3.28	+ .09
	—	.156	—	—	—	—	6.74	6.56	+ .18
	—	.351	—	—	—	—	10.14	9.84	+ .30
	—	.609	—	—	—	—	13.23	13.12	+ .11
	—	.945	—	—	—	—	16.71	16.40	+ .31
	—	1.320	—	—	—	—	19.80	19.68	+ .12
Experiments of Wm. S. Henson, at Bloomingdale, N. J., for Mr. H. H. Day. Vol. 4, p. 205.	37.00	12.0	1.25	5280.	520	.006	29.50	29.40	+ .10
	43.00	8.	—	—	—	—	19.30	20.00	− .70
	50.25	5.25	—	—	—	—	13.27	15.10	−1.83
	58.25	3.25	—	—	—	—	9.43	11.75	−2.32
	66.75	1.75	—	—	—	—	6.31	9.60	−3.29
Experiments at St. Gothard Tunnel. Vol. 24, p. 96.	82.32	5.29	7.87	15092.	531.	.006	15.32	19.99	−4.67
	63.94	3.23	—	—	—	—	13.42	16.73	−3.31
	56.45	2.79	—	—	—	—	13.29	15.97	−2.68
	77.03	3.53	5.90	1719.	541.	.006	33.04	38.05	−5.01
	60.71	1.03	—	—	—	—	19.38	30.81	−11.43
	53.65	1.54	—	—	—	—	25.53	29.76	−4.23

PRACTICAL FORMULAS FOR ANGLE BLOCKS AND BRACES OF BRIDGES.

By P. H. PHILBRICK, M. S., C. E., Professor of Engineering, State University of Iowa.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.



Let ABCD represent a panel. AD=D, AB=l

EH=L=length of brace.
EF=d=depth " "
BF=y= " " block.
BE=x=width " "
BK=h=height " "

We have $x^2+y^2=d^2$ . . . . (1)

and

$$\frac{BE}{BF}=\frac{CF}{CG};\ \text{or}\ \frac{x}{y}=\frac{D-y}{l-x} \quad . \ . \ . \ (2)$$

The exact values of x and y can be found from (1) and (2), only by solving an equation of the fourth degree.

A very simple and almost exact solution is, however, easily effected as follows:

Substitute

$$a=\frac{d\mathrm{D}}{\sqrt{\mathrm{D}^2+l^2}}\ldots(3),\text{ and }b=\frac{dl}{\sqrt{\mathrm{D}^2+l^2}}\ldots(4)$$

for x and y in the second member of (2), which equation then becomes

$$\frac{x}{y}=\frac{\mathrm{D}-b}{l-a}\quad\ldots\quad(5)$$

Now (1) and (5) give:

$$x=\frac{d(\mathrm{D}-b)}{\sqrt{(\mathrm{D}-b)^2+(l-a)^2}}\quad\ldots\quad(6)$$

$$\text{and }y=\frac{d(l-a)}{\sqrt{(\mathrm{D}-b)^2+(l-a)^2}}\quad\ldots\quad(7)$$

$$\text{Then }\mathrm{L}=\sqrt{(\mathrm{D}-y)^2+(l-x)^2}\quad\ldots\quad(8)$$

$$\text{Or }\mathrm{L}=\sqrt{\mathrm{D}^2+l^2}-\frac{2xy}{d}\text{ almost exactly; (9)}$$

$$\text{or }\mathrm{L}=\sqrt{\mathrm{D}^2+l^2}-\frac{2ab}{d}\text{ very nearly. (10)}$$

Let us compare these with the true results.

Let $d=1$, $\mathrm{D}=10$ and $l=15$.

Eq. (3) gives $a=$ .557;
Eq. (4) gives $b=$.831
" (6) " $x=$ 5354
Eq. (7) " $y=$.8444
" (8) " $\mathrm{L}=17.1187$
" (9) " $\mathrm{L}=17.1183$
" (10) " $\mathrm{L}=17.1148$

a and b are special values of x and y found from (1) and (2) by interchanging x and y in the second member of (2), or by omitting them from that member.

Supposing $y>x$ then is $l>\mathrm{D}$;

$$\text{and }\frac{a}{b}=\frac{\mathrm{D}}{l}>\frac{x}{y}=\frac{\mathrm{D}-y}{l-x};$$

and since $a^2+b^2=x^2+y^2$; $x<a$ and $y<b$.

Let $b=y-e$; then by virtue of the preceding equation, and since e is small,

$$a=x+e\frac{y}{x}\text{ very nearly.}$$

Hence b is less than, and also nearer the true value of y than a is to the true value of x. We therefore compute y first.

Also from the above we have $ab>xy$,

$$\text{therefore }\frac{ab}{d}>\frac{xy}{d}=\mathrm{BK}.$$

Now eliminating x from (1) and (2) I find:

$$y^4-10y^3+80.25y^2+5y-56=0.$$

By Horner's method (.831 being an approximate root of the above equation) I find $y=.845$. Then $x=.535$, and $\mathrm{L}=17.1187$.

The errors pertaining to the easy solution given above, decrease as $\frac{d}{\mathrm{D}}$ or $\frac{d}{l}$ decreases, or as $\frac{\mathrm{D}}{l}$ approaches unity. Still the errors are almost inappreciable, and are of no practical significance, even in the above very unfavorable case.

When the length only is wanted, eq. (10) is most convenient and is sufficiently exact.

It is easy to see that:

$\mathrm{BD}=\mathrm{EH}+2\mathrm{BK}+$ a small quantity, say e', and that $\frac{2ab}{d}=2\mathrm{BK}+$a small quantity, say e'', $\therefore\ \mathrm{BD}-\frac{2ab}{d}=\mathrm{EH}+(e'-e'')$; which shows that the error involved in eq. (10) is the difference of two small quantities.

THE SOCIETY OF CIVIL ENGINEERS OF PARIS AND FRENCH PORTS.—The tonnage of the following ports during the year 1879 was given in a paper read before this society by M. Hersent: Of Antwerp it was 5,614,243 tons; Dunkerque, 726,-401; Le Havre, 1,888,099; Rouen, 582,-951; Bordeaux, 871,930; Marseilles, 2,591,052; Genes, 2,068,973. He also called special attention to the value of the docks projected under M. Freycinet at the port of Dunkerque. M. A. Pyotte-Beyaert, of that port, worked hard many years in the endeavor to get the necessary dock and harbor improvements carried out to give back to Dunkerque the important position it once held among the ports of France. As long ago as 1868 he caused fully matured plans and estimates to be lithographed and largely circulated in the endeavor to improve the port.

ON SOME ELECTRO-MAGNETIC ROTATIONS OF BAR MAGNETS AND CONDUCTING WIRES ON THEIR AXES.

By G. GORE, F.R.S.

Proceedings of the Royal Society.

In all the published forms of Ampère's experiment of the electro-magnetic rotation of a vertical bar magnet or conducting wire upon its axis by Ampère, Faraday, Sturgeon, and others, the magnet or wire has either been immersed a large portion of its depth in mercury, or its middle part has been connected by a wire with a surrounding annular channel filled with mercury, and the electric current passed into or out of the magnet or wire by means of that liquid, and the mercury has formed an essential part of the arrangement.

In different treatises on electro-magnetism, either no explanation or different ones are given of the cause of the rotation of the magnet or wire. The most usual cause assigned is the action of the portion of current in the mercury and the fixed conductor immersed in it upon the current in the rotating wire or magnet; and the correctness of this explanation is proved by the simultaneous movement of the mercury in the opposite direction.

De la Rive, in his Treatise on Electricity (English edition, 1853, vol. i., page 259) very correctly remarks: "It must not be supposed that the phenomenon of rotation is due, as has been erroneously stated, to the action upon the magnet of the portions of the current that traverse it, or that traverse the conducting wires attached to the magnet and move with it. In fact, how could a solid system be set in motion by a force emanating from a portion of the very system itself, and connected with it in an indissoluble manner? The action can only arise from a part of the current which is independent of the system that moves. This part is the portion of the circuit which is not connected with the magnet that is set in rotation, and which consequently is situated independent of the system in motion. This kind of action has been calculated by M. Ampère in a perfectly rigorous manner."

Although the action of the portion of the current in the mercury and the fixed conductor in contact with it upon the movable current in the rotating wire or magnet is a cause of the movement, there are other circumstances which co-operate to produce the rotation, and which are themselves capable, without assistance, of producing it. Wiedemann and myself have shown that an electric current passing from one end to the other of a magnetized iron rod or wire having *dissimilar* poles at its two extremities produces torsion of the wire (the two ends of the wire moving of course in opposite directions), and that reversing the direction either of the current or of the magnetic polarity, reverses the direction of the twist. In all published cases of rotation of bar magnets on their axis by the influence of electric currents, the two ends of the magnet have had *dissimilar* poles. By meditating upon certain facts connected with this subject, I concluded that, by passing a current from one end to the other of a magnetized rod or wire having *similar* poles at its two ends, the magnet would probably rotate; and experiment has demonstrated that conclusion.

Upon a thin wooden tube 15 centims. long and 7 millims. bore I wound a cotton-covered copper wire 1.7 millim. diameter from one end of the tube to the middle, then reversed the direction of winding and continued to the other end and back to the middle, again reversed and coiled to the first end of the tube; by which arrangement the passage of a current through the coils produced two similar poles at the ends of the tube, and two others of the opposite kind at the middle.

The tube being now fixed in a vertical position, a straight iron wire 15 centims. long and 1.8 millim. diameter, pointed at its lower end and surmounted by a brass mercury cup 5 millims. diameter, containing a drop of mercury, was sup-

ported entirely within the tube and free to rotate, by a similar cup (surmounting a fixed vertical brass rod) at the lower end of the tube, the upper end of the axial wire being kept in position by a vertical brass rod fixed above the coil, and terminated at its lower end by a sharp point of platinum in the mercury cup.

A current from 6 one-pint Grove's elements arranged as 3 being now passed through the coil, brass rods, and axial wire, the latter rotated rapidly.

With a downward current through the axial wire, and north poles * at the ends of the tube, the upper end of the wire rotated in the same direction as the hands of a watch. Reversing the direction of the current either in the coil or iron rod, reversed of course the direction of motion. The rotation in this case was not due to obliquity of coil-current, because that was neutralized by the second layer of coils; nor to portions of transverse currents proceeding to or from the brass rods, because each of those portions was 10 centims. distant from the ends of the axial wire; nor was it due to the portions of current entering or leaving the coil, because they entered and left at the same part and in parallel directions, and thus neutralized each other's effect. A copper wire substituted for the iron one would not rotate, probably because copper is so little capable of acquiring longitudinal magnetism.

To ascertain if the rotation was merely due to an action of the current in the coil upon either the axial current or longitudinal magnetism of the iron, or whether the coil current simply performed the function of longitudinally magnetizing the axial wire, I took an iron wire 23 centims. long and 2.7 millims. diameter, sharp pointed at its lower end, soldered to its upper end a double wire of cotton-covered copper, each wire being 1.7 millim. diameter, coiled the double wire upon the axial rod in two layers (so as to enable two *similar* poles to be formed at the extremities of the axis), and terminated the copper wires by a little brass mercury cup just above the top end of the vertical iron axis. By supporting this apparatus as the axial wire in the previous experiment, and passing the current, rotation occurred, showing that the chief use at least of the coil current was to impart longitudinal magnetism to the axial wire, and that the rotation was not simply due to any reaction between the coil and that wire. Reversing the direction of the current did not reverse the direction of rotation. In another experiment similar to this, I formed about 12 centims. in length of the middle part of the axial wire of copper instead of iron, and obtained similar rotation; but as copper is only slightly capable of acquiring longitudinal magnetism from a coil current surrounding it, a precisely similar apparatus having an axial wire composed entirely of that metal would not rotate.

These experiments and the following ones produce a striking effect in a lecture, because the rotation appears to be produced without reaction of the moving part of the apparatus upon any external or fixed body.

To determine whether the longitudinal element of the coil current obtained by obliquity of winding of the wire might be substituted for the longitudinal current through the magnet, I took an iron wire 13 centims. long and 1.7 millim. diameter, sharp-pointed at its lower end, soldered near to that end one extremity of a cotton covered copper wire 1.7 millim. in diameter, coiled the latter in one direction to the middle part of the iron wire, then reversed the direction of winding and coiled to the other end of the iron, and terminated the coil by a little brass cup just above the upper end of the iron wire as before. By supporting this apparatus as in the previous experiments, and passing the current, rapid rotation took place, proving that a longitudinal current in the iron itself was not necessary.

To ascertain whether the longitudinal element of the current was essential to the motion, I constructed a similar apparatus to the last, but instead of attaching the upper end of the coil wire direct to the brass cup, I continued the copper wire vertically downwards to the bottom of the coil, to neutralize the effect of obliquity of winding; then carried it outwards and upwards in the form of a large rectangle 5 centims. distant from the coil and on to the mercury cup. On

* By a North pole I mean that which points to the South, and by a South one that which seeks the North.

passing the current rotation occurred freely, showing that the longitudinal current was not essential to the motion. This experiment, and that described in paragraph 4, appears to prove that the rotation is not an effect of any obliquity or spiral arrangement of the axis of the magnetized iron molecules with regard to the axis of the wire, produced by the combined action of the transverse and longitudinal elements of the current in the coil, because the latter element was neutralized, but that it is an effect of the tangential poleless magnetism in the fixed wires above and below upon the longitudinal magnetism of the movable iron axis and its coil.

As an electric solenoid, however, possesses in some degree many of the properties of a magnet, its longitudinal magnetism, though feeble, must have operated in some of the previous experiments; and I therefore now tried to obtain rotation of one by the action of vertical currents. Upon a very thin wooden tube 15 centims. long and 12 millims. external diameter, I coiled a single stout cotton-covered copper wire from one end to the other, reversing the direction of winding at the middle of the tube, and surmounting the upper end of the wire by a small brass cup containing mercury. The lower end of the wire was sharply pointed, and the coil was supported as in the previous experiment. By passing the current from 6 one-pint Grove's elements arranged as 3, faint signs of rotation were observed.

In each of these cases of rotation an upward vertical current entering a lower south pole or leaving an upper one caused the upper end of the rod to rotate in the direction of the hands of a watch, and a downward current entering or leaving a north pole also produced that direction of motion, and reversing the poles in either case reversed the effect.

In each of these instances of rotation, without the aid of a current near the middle of the magnet, the coil being so constructed that the current in it could not be reversed without reversing that in the fixed conductors near it, reversing the direction of the current did not reverse that of the rotation, because the two acting influences were reversed together; and therefore each apparatus had its own direction of rotation, either right-handed or left-handed ( )*, according to the direction in which its coils were wound. It follows from this that a current, the direction of which is alternately reversed, will drive the apparatus quite as well as one in one uniform direction.

As the rotation was apparently due to the influence of the tangential poleless magnetism of the portions of vertical current in the fixed conductors upon the longitudinal magnetism of the vertical iron axis and its coils, I now endeavored to increase the effect. For this purpose I substituted for the upper brass rod a fixed coil consisting of one layer of copper wire upon an iron wire axis, but having dissimilar poles at its ends and no poles at its middle part, and placed between it and the lower brass rod a similar right-handed one to that described in paragraph 6 and free to rotate. The opposed poles of the fixed and movable coils were of opposite kinds, *i. e.* north and south. On passing a current from a Noe's thermopile of 96 elements † connected as 24, rapid rotation in a right-handed direction occurred. I now substituted for the lower brass rod another fixed coil, similar to the upper one, but of an opposite direction of polarity, and passed the current again; still more rapid rotation in the same direction took place, and the effect was very striking. In this latter instance two south poles free to move were opposed to two fixed north poles, and in each instance the current was passed upwards. In the second experiment also the longitudinal magnetic influence of each opposed iron axis and coil acted upon the tangential magnetism of the longitudinal element of the end of the copper coil current opposed to it, and thus both the longitudinal and the tangential magnetism of each of the four opposed ends co-operated to produce a most effective result.

With a thicker axial wire in the moving coil the rotation was not so rapid; and with an axial wire of the usual thickness, but a double layer of copper wire coils, and the current passing through the axial wire, the rapidity of rotation was not much altered, probably because the

* By a "right-handed" coil, I mean one the upper end of which rotates in the same direction as the hands of a watch.

† I have found this apparatus very convenient for such experiments.

increased weight and friction counteracted the effect of the increased magnetism. By substituting for the right-handed movable coil with south poles at its extremities, in these experiments, a left-handed one with north poles at its ends opposed to north poles of the fixed ones, and passing the current, no rotation occurred: in this case the longitudinal element of the current in the movable coil, acting upon the longitudinal magnetism of the fixed iron axis and its coil, tended to produce rotation in one direction, and the longitudinal magnetism of the movable axis and its coil, acting upon the longitudinal element of the current in the fixed coil, tended to produce rotation in the opposite direction.

I now substituted for the movable coil a vertical wire of iron 13 centims. long and 1.7 millim. diameter, surmounted by a small brass mercury cup, passed the current from the thermopile, and obtained rotation, but less rapid than before, probably because of the less degree of longitudinal magnetism; but by enclosing this wire in the axis of a fixed coil which produced appropriate and similar coils at its two ends, as in paragraph 4, and repeating the experiment, very great velocity of rotation was obtained. Rotation of a somewhat thicker wire of nickel was also obtained, both with and without the aid of the current in the middle fixed coil. I also tried, without the aid of the middle fixed coil and with it, a copper wire of similar dimensions to the iron one, and obtained rotation freely; in this case the motion was probably nearly wholly due to the action of the longitudinal magnetism of the adjacent ends of the fixed axial wires, and their coils upon the tangential magnetism produced in the movable copper wire by the axial current. Each of these rotations agreed in direction with those of the movable coil.

I also obtained rotation of the iron wire whilst the wire was in a horizontal position, its ends resting in hollows in the ends of the iron axis of the two fixed coils, and the ends of those axis and of the movable wire lying upon the surface of pools of mercury in small watch glasses. The movable iron wire was enclosed in the axis of a thin iron tube within a fixed coil, having appropriate and similar poles at its ends. The current from the thermopile produced very rapid rotation. This result proves that the rotations are not due to terrestrial magnetic influence.

As the directions of magnetic polarity, electric current, and rotation agree with those in the different forms of Ampère's experiment, and as in most, if not all, of the previously known cases of rotation of a bar magnet or conducting wire on its axis an electric current passes through the end of the bar or wire, it is evident that those rotations were due, not only to the portions of current in the mercury and fixed conductors connected with it near the middle of the magnet or wire, but also to the influence of the currents in the fixed conductors near the ends of the magnet or wire.

[NOTE.—It having been suggested by Professors Maxwell and Stokes that the rotation in the foregoing experiments was due to the influence of the portions of current in the cups of mercury, or in the fixed conductors near the ends of the movable wire or magnet upon the movable magnet, I diminished the internal diameter, both of the upper and lower cups, from 4 millims. to 1.75 millim., and arranged the following apparatus and experiment.

The fixed upper wire was of brass, 2.5 millims. diameter and 60 millims. long; it had no coil upon it, and was used as a conductor only; its lower end terminated in a fine point of a steel needle projecting 6 millims. The lower fixed wire (also used as a conductor only) was of platinum, to resist the action of the mercury; it was 2.3 millims. diameter and 75 millims. long, with a cavity in its upper end 3.5 millims. deep and 1.75 millim. diameter, and containing a thin plate of ruby in its lower part, with a minute hole in the center for the needle point to rotate in. The movable wire was 2.5 millims. diameter and 125 millims. long, its upper half being composed of soft iron and its lower half of brass; its lower end terminated in a needle point like that of the upper fixed wire, and its upper end had a cavity and perforated ruby plate like that in the lower fixed wire. A voltaic coil 60 millims. long and 7 millims. internal diameter, composed of four layers of cotton covered with stout copper wire, was used to magnetize the iron half of the movable wire, and

fixed by means of a separate support in a proper vertical position beforehand, so as to enclose in its axis the iron wire portion only. The little cups were also each half filled with a minute globule of mercury before putting the movable wire into its place.

After adjusting the wire so as to make rotation easy, a current from 6 Grove's elements of one-pint capacity arranged as a series of 6, also as a double series of 3, was passed through the coil and vertical wires, and the direction of the portion of the current in the coil alone, also in the vertical wires alone, was varied; but notwithstanding that plenty of current passed, no signs of rotation could be detected. These results, therefore, strongly support the opinion that the rotation in the experiments was due to the action of the portions of the current in the cups of mercury.]

ON THE ACTION OF COKE SLAG ON FIREPROOF MATERIALS.

By Dr. B. KOSMANN.

From "Abstracts" of the Institution of Civil Engineers.

THESE experiments were undertaken with the object of ascertaining what relation exists between the composition of the fused slag resulting from the combustion of coke at a high temperature and the deterioration of the fire bricks subjected to the action of such slag. At the same time and for the purpose of comparison, analyses were made of the ash produced by the same coke when burned at a lower temperature. It has been usual, in investigating the action of the slag produced by fuel upon fire-proof materials, to analyze the ash of the fuel before it has undergone fusion. That such a practice must, in many cases, lead to erroneous conclusions may be seen from the examples given below. The experiments were conducted in regenerator furnaces for heating gas retorts. In these furnaces the fire bricks, especially in the neighborhood of the slits through which air is admitted, are very rapidly corroded, unless their composition is adapted to the acid or basic nature of the slag with which they are brought into contact.

The first series of experiments was made with a regenerator furnace on Müller and Eichelbrenner's system. The coke used was from the Gelsenkirch district, and contained 11.92 per cent. of ash. When produced at a temperature which did not suffice to fuse it, the composition of this ash was that given under A. B is the ash of the same coke fused at the temperature prevailing in the furnace:

	A.	B.
Silica	47.91	62.95
Alumina	30.17	25.23
Ferric oxide	12.16	—
Ferrous "	—	3.12
Manganic "	0.38	—
Manganous "	—	0.28
Lime	1.41	0.46
Magnesia	1.23	0.92
Soda	2.60	2.82
Potash	3.34	3.51
Sulphuric acid	0.82	—
Phosphoric "	—	0.55
Metallic iron	—	0.09
Ferrous sulphide	—	0.04
	100.01	99.97

The fused slag formed a dark glass of the specific gravity 2.52, and enclosing globules of metallic iron. At the higher temperature, therefore, both iron and manganese had been reduced to lower stages of oxidation, part of the former even to the metallic state. The sulphates of lime and magnesia had been either volatalized or removed by mechanical means, and the potash and soda remained in the slag. Although the ash is of a decidedly basic character before fusion, yet the slag produced from it is acid. In this case the use of fire bricks with an excess of acid constituents was indicated. Those used contained 89 per cent. of silica, and resisted the action of the fused slag remarkably well.

In the second series of experiments

the regenerator furnace was constructed on Liegel's system. The coke was made from a mixture of $\frac{2}{3}$ Nettlesworth and $\frac{1}{3}$ Leverson coal. The proportion of ash in the coke was 9.24 per cent.; its analysis is given in the following table under A. After the furnace had been working for three days the sample B was taken. It was but partially fused, the action of the furnace being imperfect, owing to the air slit being too large. When this had been reduced in size the slag was easily fused, and had the composition C:

	A.	B.	C.
Silica	43.34	51.80	34.55
Titanic acid	0.86		3.40
Alumina	21.16	29.27	41.26
Ferric oxide	11.84	11.24	—
Ferrous "	—	—	0.43
Manganic "	0.61	1 26	—
Manganous "	—	—	0.25
Lime	10.53	6.85	15.14
Magnesia	0.41	1.12	0.57
Soda	0.86	0.33	0.06
Potash	1.88	0.70	0.67
Sulphuric acid.	7.17	—	—
Phosphoric " .	0.61	—	—
Sulphur	—	—	0.19
Metallic iron	—	—	3.75
	99.27	102.57	100.27

The apparent excess in B is due to the oxygen of the iron and manganese compounds, part of which were present in the lower stage of oxidation. The presence of titanic acid is remarkable in these analyses. The changes which took place during the first stage of fusion (B) were not important. In the second stage (C), when completely fused, the slag became more basic in its character than the ash from which it was derived. There was a considerable reduction of metallic iron, which was found in numerous globules interspersed throughout the dark, vitreous mass. In this case also the sulphates had been volatilized. The iron globules were very impure, containing only 36 per cent. of metallic iron.

After the furnace had been in work some months the draught became defective, and, on the flues being opened, they were found lined with a $\frac{3}{4}$ inch coating of a light, porous substance, which was found on analysis to contain 72 per cent. of silica and a large proportion of sulphates. It probably owed its origin to the decomposition of the slag by steam, assisted by the action of the sulphates present. This furnace was lined with fire bricks containing as high a proportion of alumina as possible; they resisted the action of the basic slag so well that their wear was almost imperceptible.

The coal used in the third series of experiments was from Upper Silesia, and contained 3.54 per cent. of ash, of the composition given below under A:

	A.	B.
Silica	61.18	61.32
Alumina	26.07	23.79
Ferric oxide	7.32	—
Ferrous "	—	7.41
Manganous "	—	0.78
Lime	1.32	3.60
Magnesia	1.18	1.50
Soda	0.33	0.80
Potash	1.79	1.35
Loss as gas	0.47	—
	99.66	100.55

The regenerator was lined with the best Garnkirk fire bricks; but, as will be seen from the analysis B, the slag was of so acid a nature that these bricks were speedily corroded, and in a short time completely destroyed. Other bricks, containing 89 per cent. of silica, were therefore substituted, and left nothing to be desired with regard to durability. —*Journal fur Gasbeleuchtung.*

In the early future india-rubber ought not to be an expensive article. According to information concerning the plant which produces Ceara rubber, contained in the report on india-rubber by Dr. H. Trimen, of Ceylon, the plant is very hardy, and will grow in a dry, rough soil, and a moderately dry, hot atmosphere, while the Para and West India rubber plants require a rich alluvial soil, and a constantly hot-moist atmosphere. Ceara-rubber plants have been found to succeed in Ceylon, Calcutta, and Madras, but the climate of Singapore is too wet for them. It is suggested, says the *Journal of the Society of Arts*, that plantations should be formed on exhausted coffee land. The tree grows to about thirty feet or more in height, and forms a dense rounded crown. It attains a diameter of four inches or five inches in about two years, when it may be tapped.

ON THE DISCHARGE OF WATER THROUGH SLUICES AND SIMILAR ORIFICES.

By K. R. BORNEMANN.

Foreign Abstracts of Institution of Civil Engineers.

THE first part of the paper treats of the flow of water through submerged sluices, and the author gives the results of an extensive series of observations made by himself with a view of determining the coefficients of discharge for such cases. The experimental sluices were made by placing a flat board across a parallel trough, the board resting against a strip on each side, the bottom of the opening being formed by and flush with the bottom of the trough. The height of the opening was varied by raising or lowering the sluice board, and three different widths of troughs and sluices were used. In experiments 1 to 16 the trough was 1.135 meter wide (44.7 inches), and the clear opening 1.006 meter (39.6 inches) wide; in experiments 17 to 44 the trough was 0.544 meter (21.42 inches), and the opening 0.520 meter (20.47 inches) wide; and in the final series 45 to 63 the trough measured 0.802 meter (31.75 inches) wide, and the opening 0.774 meter (30.47 inches) wide.

In the above experiments weir boards were inserted in the trough about 11 feet 4 inches below the sluice, so as to pond up the tail water sufficiently to submerge the issuing stream.

Let Q = quantity of water discharged in cubic meters per second.

a = height of opening.
b = breadth of opening.
h_1 = height of surface of head water above top edge of opening.
h_2 = height of surface of tail water above top edge of opening.
k = head due to velocity of approach of head water.
μ = coefficient of discharge.

} meters.

Then $$\mu = \frac{Q}{ab\sqrt{2g\,(h_1 - h_2 + k)}}.$$

g being the acceleration due to gravity.

The effective head $(h_1 - h_2 + k)$ varied from 21 millimeters to 231 millimeters (0.83 to 9.09 inches).

The author endeavors to find an empirical formula from which μ can be calculated so as to agree with the experiments. He tried successively eleven different formulæ, and determines the coefficients in each case from the experiments by the method of least squares. The two formulæ which give the most satisfactory results for submerged discharge are

$$\mu = \alpha + \beta \frac{\sqrt{a}}{h_2 + \frac{a}{2}};$$

$$\mu = \alpha + \beta \sqrt{\frac{a}{h_1 + \frac{a}{2}}} + \gamma \frac{1}{\left(h_2 + \frac{a}{2}\right)\sqrt{b}}.$$

With the experimental sluices he finds as the most probable values of the coefficients for the whole sixty-three observations:

For the first formula
$\alpha = 0.54138$; $\beta = 0.14965$

For the second formula
$\alpha = 0.43479$; $\beta = 0.25666$; $\gamma = 0.031212$.

The author also gives some experiments on submerged discharge communicated to him long ago by Weisbach. In these the trough was 0.363 meter (14.29 inches) wide, and the opening the same, there being no side strips. The bottom edge of the sluice was also beveled off on the tail water side. The conditions of experiments vary too much, and their number is too few to deduce reliable formulæ from them.

This part of the paper also contains a critical examination of some formulæ proposed by Linnenbrügge, and published in 1879 in the *Civilingenieur*. These formulæ the author considers unsatisfactory.

The second section of the paper deals

in similar manner with the best extant observations on free discharge from sluices; the data used being the experiments by Weisbach, by Boileau, and by Lesbros.

The empirical formulæ for the coefficient of discharge are as follows: the head to the *center* of the opening being h, and the clear height and width a and b as before, all in meters.

For sluices built across a trough 0.9 meter (35.4 inches) wide, the opening reaching the whole width, and the bottom being flush, along the top of opening only, for heads to 0.580 meter (22.8 inches)

$$\mu = 0.5805 - 0.01898\sqrt{\frac{a}{h}} + 0.00144\left(\frac{1}{a}\right).$$

For sluices 0.364 meter (14.33 inches) wide, and of a similar construction, but with the lower edge of the sluice rounded, and with low heads

$$\mu = 0.8624 - 0.2194\sqrt{\frac{a}{h}} + 0.00219\left(\frac{1}{a}\right).$$

For sluices 0.6 meter (23.62 inches) wide, in which the bottom and sides of the opening are distant from the sides of the trough, so that contraction takes place all round, for heads to 1.800 meter (5 feet 11 inches)

$$\mu = 0.5732 + 0.01355\sqrt{\frac{a}{h}} + 0.02109\sqrt{\frac{1}{a}}.$$

For sluices similar to the last, but with guide strips all round the opening, 5 centimeters (2 inches) from the edge, for heads to 1.800 meter

$$\mu = 0.4488 + 0.06293\sqrt{\frac{a}{h}} + 0.5122\frac{b}{2(a+b)}.$$

The author remarks upon the great variation which the above coefficients show, and considers that till a much greater number of systematic experiments have been made, the use of sluices for gauging water is only permissible in those cases in which the conditions and dimensions are within the limits of those of the present experiments.

The third section of the paper discusses the experiments by Poncelet and Lesbros on the discharge through orifices in thin plates. Retaining the notation as in the second section, the author finds:

The rectangular orifices 0.200 meter (7.87 inches) wide, and with contraction all round; for heads up to 1.800 meter (5 feet 11 inches)

$$\mu = 0.5951 + 0.01360\sqrt{\frac{a}{h}} + 0.0008844\left(\frac{1}{a}\right).$$

And for similar orifices 0.020 meter (0.787 inch) wide

$$\mu = 0.6262 + 0.003291\sqrt{\frac{a}{h}} + 0.0002063\left(\frac{1}{a}\right).$$

For openings 0.200 meter (8 inches) wide, but without contraction along the bottom edge

$$\mu = 0.5074 + 0.02126\sqrt{\frac{a}{h}} + 0.3958\frac{b}{2(a+b)}.$$

For orifices 0.200 meter wide, with contraction along the top and bottom, but not at the sides

$$\mu = 0.6550 + 0.03611\sqrt{\frac{a}{h}} - 0.07884\left(\frac{a}{a+b}\right).$$

For orifices fitted with a trough-shaped mouthpiece in front, and contraction at the top and sides, but not at the bottom

$$\mu = 0.6945 - 0.1364\sqrt{\frac{a}{h}} + 0.005651\frac{b}{2(a+b)}.$$

For similar orifices, with contraction at the top and the bottom, but not at the sides

$$\mu = 0.6967 - 0.1033\sqrt{\frac{a}{h}} - 0.06244\frac{a}{a+b}.$$

An appendix to the paper examines the formulæ given by Weisbach and Grashoff for correcting coefficients of discharge for partial or incomplete contraction; the author finds that these all fail when used beyond the limits of the observations from which they were determined.—*Der Civilingenier.*

An English engineer recently returned home from a visit to American steel works, where enormous output is secured per converter, says: "They do it, I do not know how, but the men seem smarter, everything is ready, and the men follow each other up in their duties with rapidity and intelligence."

AN INSTRUMENT FOR THE DETERMINATION OF LATITUDE.

By S. C. CHANDLER, Jr.

From Proceedings of the Society of Arts.

It requires a great deal of temerity to claim anything novel in the determination of time and latitude, and even more to claim an improvement in this respect. Nevertheless, I believe that the principle involved in the instrument I have devised is novel, for, after a careful investigation, I have not been able to discover any instance where it has been used in the same way.

The nearest approach to it, in previous constructions, is to be found, I believe, in the floating collameter which Captain Cater invented in 1805, for obtaining the zero point of a vertical graduated circle; but no one seems to have had the idea of floating a telescope on mercury. Thus far the astronomical transit instrument has been the universally acknowledged means for the accurate determination of time. Astronomical transits vary in size, from those which are as small as the ordinary surveyor's transit to those of eight inches aperture and ten feet focal length, and two or three thousand pounds weight. These instruments are placed in the plane of the meridian, and it is intended that, as the telescope turns in the Y's, its axis shall remain always in the plane of the meridian.

The measurement of time means merely the measurement of the angle which a point in the celestial sphere has described.

In order to determine the error of a time-piece, therefore, by means of the transit instrument moving in the plane of the meridian, it is only necessary to observe by means of this time-piece the time at which a certain star crosses the meridian, and then, knowing the time at which it should cross the meridian, we have in the difference the error of the clock.

Certain difficulties are met with, on account of the inaccuracy of the construction, and of these the following four are the principal ones, viz.;

1. Error in pivots. The axles on which the telescope turns cannot be made perfectly circular, and are not of absolutely the same size; and this deviation from the perfectly circular form, and from absolute equality in size, causes irregularity in the motion of the telescope.

2. Error in collimation. This error is due to the telescope not being perpendicular to the axis on which it turns; and causes the telescope to describe a small circle of the heavens to one side of the meridian. The correction for this is determined by observing some slowly moving star, and then, before it has crossed the field, reversing the telescope in the Y's and observing again.

3. Error in level. The deviation of the instrument, on account of the axis on which it turns not being horizontal, is ascertained by means of a level supported on the two pivots, the errors of the level itself being eliminated by reversing it.

4. The error in azimuth has to be determined by astronomical observations.

We thus have in the transit four errors to be allowed for, viz.: error in pivots, in level, in collimation, and in azimuth. In the instrument which I have devised three of these errors are eliminated, and there only remains one error, which is analogous to the error in collimation of the transit.

This instrument, made by Mr. Clacey, of this city, consists of a base of walnut with approximate leveling screws at the four corners. From the middle of this base rises a pillar of black walnut, firmly bolted to the base, and surrounded by collars of hard brass. An outside sleeve of hard brass, which turns on these collars, supports the remainder of the instrument—this sleeve being rotated in azimuth by a rack and pinion movement, and provided at its base with a graduated setting circle. On top of this sleeve is a wooden cross head which supports a wooden trough in the form of a hollow rectangle, and in this trough is placed

mercury to a depth of one-eighth of an inch. The trough is constructed of wood instead of brass, because the mercury would attack brass. Whether it would be better to use cast iron is an open question.

In this trough, on the mercury, there floats a wooden float, also in the form of a hollow rectangle, and nearly as large as the inside of the trough, this float being held in position at the middle of the two sides by two cast iron pins which move in vertical slots in the sides of the float, and which are sufficiently loose not to interfere with its floating freely, but which serve to prevent any violent or sudden motion.

The above-mentioned float has attached to it two brass arms which support the telescope, the latter projecting through the hollows of the hollow rectangles of the float and trough.

The trough is not supported in the middle, but nearer one end, in order to allow of zenith observation; and on this account a counterpoise is attached at the other end of the trough.

The attempt has also been made to so proportion the parts as to bring the center of gravity of the floating part as near the axis of oscillation of the telescope as possible, in order to reduce oscillations due to jars, etc.

The illumination is effected by a series of reflectors, and comes from the side. The cross hairs are horizontal, and not vertical as in the transit. The reason for this will be explained later. In using the instrument the telescope is set at a certain inclination to the vertical, and, as the instrument is rotated in azimuth, the line of sight sweeps out a horizontal, small circle of the heavens, *i. e.*, a circle of which the zenith is the pole.

For the determination of the zenith, the free, upper surface of a liquid is used, and we have dispensed with the error of pivots, the error of level and the error of azimuth, and have left only what is, in a certain sense, analogous to the error of collimation in a transit instrument, the characteristic of both errors being that the telescope describes a small circle parallel but very close to the circle in which it is intended to revolve. The amount of this deviation in this instrument is not, however, determined by reversals of the telescope, as in the case of the transit, but by observation of the stars, in a similar way to that by which the azimuth error of the transit is found. As to the disturbance of the instrument by oscillations, the most violent oscillations I have been able to produce have required thirty seconds to have their effect dissipated, and after this time had elapsed the instrument is as quiescent as though it were mounted on stone.

It is, of course, specially adapted for observing equal altitudes, and can also be used to observe the transit of stars across any desired small circle having the zenith for a pole, and hence the reason why the cross hairs are horizontal instead of vertical.

All observations are influenced by refraction, but refraction operates to elevate all the stars equally at the same time. Hence, we can disregard the error of refraction in a series of observations, taken so near each other that there is no probability that the coefficient of refraction of the air has changed, and we can simply account it as part of the instrumental error; it having the same coefficient, hence, when the observations are reduced to middle time, this error is almost wholly eliminated. Next, as to the results that can be obtained by this instrument, I have not yet been able to make a great many observations, but those that I have made encourage me to believe that when as good mounting is given to it as is given to an astronomical transit, better results can be obtained with it than with the latter. I have used it very roughly, making observations from the roof of my house, which was subjected to a constant jarring from the teaming in the street below, and where the instrument was exposed to the wind.

All the observations that I have made are the following:

Showing the determination of clock correction on various dates, by combining stars in pairs, east and west, after latitude correction had been introduced. It should be noted that the instrument is of one and three-quarters inches aperture, and twenty-five inches focal length, provided with but five threads, whose intervals have, as yet, been only imperfectly determined, and that it was mounted in the open air, over a box of sand, and was entirely unprotected from the wind.

The observations of the 5th of January were made from the middle of the roof of a four-story dwelling.

January 25, 1880.

Chronometer Correction.

1st pair	−24.93	seconds	of	time.
2d "	−25.12	"	"	"
3d "	−25.06	"	"	"
4th "	−25.08	"	"	"
5th "	−25.06	"	"	"
6th "	−25.14	"	"	"
7th "	−25.06	"	"	"
8th "	−24.99	"	"	"
9th "	−25.11	"	"	"

February 8, 1880.

1st pair	+38.06
2d "	+37.92
3d "	+38.03
4th "	+38.02
5th "	+38.14
6th "	+38.25

From Roof.

January 5, 1880.

1st pair	−6.34	seconds	of	time.
2d "	−6.13	"	"	"
3d "	−6.12	"	"	"
4th "	−6.31	"	"	"
5th "	−6.15	"	"	"
6th "	−6.62	"	"	"
7th "	−6.44	"	"	"

1880.	No. of Stars Observed.	Probable Errors.	
		Of Chron. Correction.	Single Observation.
Jan. 5.	15	±0.040	±0.156
Jan. 25.	21	±0.045	±0.206
Feb. 8.	16	±0.047	±0.183

The following were the probable errors on nights when observations were made for both latitude and time, the large probable errors being due to the use of stars near the meridian, which move very slowly in altitude:

1880.	Stars Observed.	Probable Error.	
		Chron. Correction.	Single Observation.
Jan. 31.	14	± .087	±0.323
Feb. 5.	15	± .061	±0.355

The following are the results for latitude:

1880.	Latitude.	Probable Error.
January 31	42° 20′ 24.″95	±0.″90
February 5	42° 20′ 24.″80	±0.″85
February 8	42° 20′ 23.″25	±0.″84

The above are all the observations taken thus far, and form an exceedingly good set of results. I have not at present access to any results obtained with portable transits of the same size, with which to compare them, but do not believe that as good results can be obtained with the latter instruments. I have, however, compared my results with those of larger coast-survey transits, and mine are the best.

I have not yet determined all the constants of the instrument. I find that the wind does interfere with it somewhat when employed in the open air, and unprotected, but the deflections from this cause are but momentary, and errors due to a draught would be nearly eliminated were a greater number of cross hairs used.

Next, as to latitude. The transit instrument, when placed in the meridian, is used only for time; it can be used for the determination of latitude if placed in the prime vertical. The Coast Survey have introduced for this purpose the zenith telescope, and have obtained with it the very best results. To compare my instrument with this is a very severe test; but it will be seen that, although I have had only three evenings on which I could make observations for latitude, the results obtained are remarkably good. The claims, therefore, that I make for my instrument are the following, viz.:

1. The ability to use any part of the heavens that are not obscured by clouds. In using the transit it is often impossible to obtain observations when clouds hang in the meridian, even though there may be any amount of clear sky on either side. With my instrument we can use any region of clear sky in the heavens, as we can use any horizontal circle whatever; although the use of the same circle all the time renders the computations easier.

2. There is only one instrumental error to determine inatead of four.

3. This instrument is unaffected by errors in mounting.

4. Simplicity in use; requiring no readings of level nor reversals. In the use of the transit about one-half the time is taken up by these processes, which are unnecessary with my instrument.

5. The construction is very cheap.

6. Combination of a time and latitude instrument in one.

7. It admits also, of the application of a delicate micrometer on an entirely new principle, as a micrometer screw carrying a weight could be mounted on the float, thus enabling us to move the center of gravity of the floating part, and to tilt the axis of the telescope. We can thus apply here the same methods that we can in the zenith telescope.

THE BEHAVIOR OF RAILWAY CARRIAGES IN PASSING CURVES.

By F. HOFFMANN.

Foreign Abstracts of the Institution of Civil Engineers.

THE author draws attention first to the case of a simple wagon with rigid wheel-base, and on each of whose axles two wheels with coned tires are immovably fixed. He gives the most general form of equation between work and resistance on a curve, and thence derives the form it takes in practical cases, viz.,

$$K=Gf\left(\frac{L}{R}+\frac{s}{R}-\frac{1-a}{1+a}-\frac{1-b}{1+b}\right) \quad \ldots (1)$$

where K is the resistance, G whole load on one axle, f coefficient of friction, L wheel base, R radius of a curve, s the width of gauge from center to center of rails, a ratio of running radius of inner to that of outer wheel on front axle, and b the same ratio for hind axle. The part $Gf\frac{L}{R}$ is due to transverse sliding, the rest to the rotation of one wheel about the other on each axle. This expression shows that the resistance is small for light load, smooth rails, narrow gauge, short wheel-base, large radius of curvature, and values of a and b near the limit $\frac{R}{R+s}$.

Of the equations

$$K=Gf\frac{L}{R} \quad \ldots (2)$$

$$K=Gf\left(\frac{L}{R}+\frac{s}{2R}\right) \quad \ldots (3)$$

$$K=Gf\left(\frac{L}{R}+\frac{s}{R}\right) \quad \ldots (4)$$

$$K=Gf\left(\frac{L}{R}+\frac{2s}{R}\right) \quad \ldots (5)$$

(2) holds for both axles in outer contact, thus $a=b=\frac{R}{R+s}$; (3) for either axle in outer contact, and the other on the middle of the line; (4) for a diagonal position, thus $a=\frac{1}{b}=\frac{R}{R+s}$, or $=\frac{R+s}{R}$, or for the wagon set fairly on the middle of the line, thus $a=b=1$; (5) for inner contact of both axles, thus $a=b=\frac{R+s}{R}$.

For investigation of actual resistances and wear, the position assumed by the wagon under the conditions that generally hold in practice must be ascertained. Experience proved that the front axle of a wagon with rigid wheel-base always ran in outer contact. Theory shows that it could only be otherwise if the wheel-base were $<\frac{1}{2}$ the gauge. Less was known of the behavior of the hind axle; to solve the question trials were made on a line with curves of radii down to $8\frac{1}{2}$ chains, with wagons of 16.4 and 8.2 feet wheel-bases, in which an arrangement of mirrors showed the play between flange and rail to occupants of the wagon. It was found that the tendency of the hind axle to run in inner contact was much greater for the long than for the short wheel-base; for the latter indeed it ran in outer contact when the curvature was small. Reasons are then given for assuming the law, that the hind axle of a four-wheeled wagon with rigid wheel-base always takes a radial position if sufficient play be provided on the line. Its accuracy was confirmed by experiments with a model. Hence the distance between outer rail and outer flange of hind axle

being the height of a chord equal to twice the wheel-base is

$$\sigma_h = \frac{L^2}{2R} \quad . \quad . \quad . \quad . \quad (6)$$

but if σ the whole play be $< \frac{L^2}{2R}$, then:

$$\sigma_h = \sigma \quad . \quad . \quad . \quad . \quad (7)$$

and corresponding to these values of σ_h we have for the sine of the angle of contact of outer front wheel

$$\sin \beta = \frac{L}{R} \quad . \quad . \quad . \quad (8)$$

or $$\sin \beta = \frac{L}{2R} + \frac{\sigma}{L} \quad . \quad . \quad . \quad (9)$$

The constraint necessary to alter the position of a wagon turning a curve arises partly through the axle seats, but chiefly from the lateral pressure between the rail and the outer flange of the front axle. For the former the maximum value is $K_1 = Gf\frac{s}{R} \times f_1 \frac{d}{2r}$, where f_1 is coefficient of friction between axle and axle-seat, d diameter of an axle-arm, and r radius of a wheel; this is a consequence of the geometrical connection of the axles and wagon. The expression for the lateral pressure is

$$P_a = G\left\{\frac{f\left(1+\frac{s}{2L}\right)}{\cos\beta} + \frac{V^2}{gR} - \left(\frac{h}{s} + \sigma \tan\alpha\right)\right\},$$

where V is the velocity, g the acceleration for gravity, h the cant of outer rail, and α the angle of conicity of the tires: here no allowance is made for friction between flange and rail, but if f_2 be the coefficient, and the actual place of contact be considered, we have for lateral pressure, $K_2 = \frac{0.9 \sin\beta}{r} P_a \times f_2$. The three members of P_a are due to the force to make the front axle take its altered position, centrifugal force, and the force arising from cant. The total curve resistance is $K\gamma = K + K_1 + K_2$, and for a diagonal position of the wagon with the front axle in outer contact, which is the position occurring in practice,

$$K\gamma = Gf\left(\frac{L+s}{R}\right) + Gf\frac{s}{R} \times f_1 \frac{d}{2r} + \frac{0.9 \sin\beta}{r} P_a f_2 \quad . \quad . \quad . \quad (10)$$

where the values may be $f = \frac{1}{5}$, $f_1 = \frac{1}{25}$, $f_2 = \frac{1}{3}$, and the second member may, in most cases, be neglected. K_1 and K_2 have not, to the author's knowledge, been taken into account hitherto. K arising from horizontal shifting causes wear of the rail tops, and affects the inner rail most; K_1 causes wear of the axle seats and holders only; K_2 resembles the action of a blunt cutter, the flange of the outer front wheel being the cutter, and the inside of outer rail the object cut. For carriages in a train the value of P_a is altered by forces in the couplings, and the author investigates this effect minutely.

Dealing next with six-wheeled carriages, if to the middle axle no more than the necessary play be given by thin flanges, cylindrical are better than conical tires; but with the usual spread of gauge at curves no lateral play is required for the middle axle. If there be no spread of gauge, safety requires a lateral play of 0.2 inch only for a wheel-base suited to the curve; but a wheel-base of 19.7 feet would require 0.8 inch on a curve of 8.5 chains radius. Supposing the loads G on the end axles equal, and that on the middle axle a fraction n of each of these; so that, Q being the weight of the carriage, $G = \frac{Q}{n+2}$ and $G_m = \frac{nQ}{n+2}$, the whole resistance is—

for inner contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\left(\frac{L}{2}+s\right)}{n+2}\right\} \quad . \quad (11)$$

for outer contact of middle axle:

$$K''' = \frac{Qf}{R}\left\{\frac{(L+s) + n\frac{L}{2}}{n+2}\right\} \quad . \quad . \quad . \quad (12)$$

Comparison of these equations with (4) shows that a six-wheeled rigid-axled carriage passes curves with less resistance than a four-wheeled one of equal weight and wheel-base, if the middle axle can run in outer contact, but with greater if its play allows only of inner contact. The minimum lateral play required to allow the middle axle run in outer contact is $\frac{L^2}{8R} + \frac{\sigma}{2}$.

The cant of the outer rail, when

adapted to neutralize centrifugal force, is obtained from the equation

$$h=s\left(\frac{V^2}{gR}-\sigma\tan\alpha\right) \quad . \quad . \quad . \quad (13)$$

After treating generally of the question of spread of gauge, the author sums up with the conclusions:—1. Four-wheeled wagons with rigid wheel-base pass curves with greater safety when there is no spread of gauge, and the flanges are unworn, since the angle of contact is then diminished by half: 2. Such wagons run on curves of the minimum radii for their wheel-bases, and with the usual spread of gauge, with the hind axle in inner contact, and with less constraint than if there were no spread of gauge: 3. With the usual spread of gauge the curve resistance is less for worn-out than for unworn tires.

Security is dependent on the relations existing for the outer front wheel, and is greater—the greater the vertical, the less the lateral pressure, the smaller the angle of contact, and the more sharply rounded and vertical the places of contact between flange and rail.

The curve resistance and wear are less—the less the vertical and lateral pressure, the less the angle of contact, and the nearer the places of contact between flange and rail lie to the crown of the rail, and for the least possible rounding of these places.

A table is given with corresponding values of R, L, V, h, σ, ρ, lateral pressure, and total curve resistance of four-wheeled wagons and locomotives with rigid wheel base.

Arrangements for facilitating the use of longer carriages on curves are next considered. When a carriage constructed on the American bogie system runs on a curve, each car will clearly follow a tangential direction till it runs against the outer rail, and then assume the position natural to a rigid-axled wagon. Owing to the smallness of the distance $\frac{l^2}{2R}$ (l being the bogie wheel base) of the hind axle of each car from the outer rail equation (2) holds approximately for each; hence the whole curve resistance to produce the altered direction of the carriage is $2\,G_1 f\frac{L}{R}$, G_1 being the load on a single car axle. If, again, for a locomotive, a bogie be used in front, with a rigid axle behind, the resistance, though less than for a rigid four wheeler, is large compared with the value just given. Since bogies with more than one axle have the disadvantage of complication, and for locomotives of reducing the load on the front outer wheel, numerous systems of flexible single axles have been devised. Of these the Adams guided axle, and the Bissel front axle for locomotives, have been laid aside on account of their dependency for steady motion on the presence of two rigid axles of long wheel-base.

Mr. John Clark devised a three-axled wagon, used on Mount Cenis, in which the axle boxes were so connected by mechanism that the yielding of the middle axle through the height of a chord equal to the wheel-base caused the end axles to run radially. If λ denote the yielding of the middle axle, Φ the angular turning of the end axles, since $\lambda=\frac{L^2}{8R}$, and $\sin\Phi=\frac{L}{2R}$, the condition to be fulfilled by the mechanism is $\sin\Phi=4\frac{\lambda}{L}$, which shows that it will suit curves of any radius. With this, and the Cleminson system on the same principle, the curve resistance and lateral pressure can be almost totally removed.

For a locomotive with the Nowotny front axle, which differs from the Bissel axle in having the pivot above the middle of the line joining the wheel centers, instead of being somewhat behind this position, experience has shown that the duration of the front tires, and proportionally of the rails, is four times > for a rigid axled locomotive of the same wheel-base.

In the search for a simple system of flexible axles for wagons, the central pivot being laid aside, an arrangment allowing the journals with their covers to slide in the long direction of the wagon against single or double incline seats in the boxes, with a central holder to neutralize shocks, was adopted with success. A simpler method lay in providing suitable play between axle box and holder, with the necessary turning power between bearing spring and axle box. Several forms of couplings for flexible axles are shown by drawings.

ON THE CONSTRUCTION, PERFORMANCE, AND WORKING OF LIGHT RAILWAY LOCOMOTIVES.

By Hr. VON BORRIES, of Hanover.

Foreign Abstracts of the Institution of Civil Engineers.

THIS is an essay towards settling the conditions, leading dimensions, &c., of engines for working "secondary" or light railways, based on the general principles laid down in Germany for the construction of locomotives, and the building and working of light railways. Three different gauges are considered throughout, viz.: standard gauge (4 feet 8½ inches), meter gauge (3 feet 3⅜ inches), and ¾ meter gauge (2 feet 5½ inches).

Load per Axle.—This is the first element to be fixed in all rolling stock. In light railways the rails are proportioned to the heaviest goods wagon which will run on the line, and the weight per axle of the locomotive must conform to this. With standard gauge, where main line wagons may come over the line, the load per axle should be taken at 9 tons; with meter gauge at 7½ tons (taking 10 tons as load of wagon, and 5 tons as its weight); with ¾ meter gauge at 3¾ tons (5 tons for load, 2½ tons for weight of wagon). These figures agree with the rules of the German Railway Union, except that they give 5 tons for ¾ meter gauge, which seems excessive.

General Principles. — The leading principles should be simplicity of construction and facility of maintenance. The blast pipe should be retained, as the most economical and automatic method of forcing the fire, and the condensation of the steam, sometimes insisted on in populous districts, should be avoided as much as possible, on account of the expense. The engines should be tank engines, four-coupled or six-coupled, according to the work to be done. They should be no heavier than is required to produce the requisite tractive force by adhesion, and the speed on steep gradients should be lowered so that a boiler suited to this weight may generate the needful amount of steam. For very steep gradients, the requisite weight may be obtained by using special engines, designed to carry luggage or passengers as part of their load.* A four-coupled engine is to be preferred, unless the traffic is heavy, or the conditions unfavorable. The train officials should be reduced in number as far as possible, since each may be taken to absorb in wages from 6 to 15 per cent. of the working cost. On light railways the full services of both driver and fireman are not needed for the engine, and therefore the latter may also act as a brakesman, working not only the engine brakes, but also those in the front van, which should be placed in communication with the engine. The guard would also act as a brakesman for his own van, which should always be at the rear of the train, and no other brakesman would be necessary. Continuous brakes are not worth their expense, especially looking to the probability of goods wagons being mixed in the train; but, as a provision for emergency, such goods wagons may be fitted with lever brakes on the Exter system, which may be worked from the engine by means of a cord. The engines should have a gangway at each side, and provision at each end for stepping on to an adjoining vehicle.

Provisions against Fire and against the frightening of Horses.—The danger of fire must be completely obviated by proper spark catchers or extinguishers, and by closing in the ash pan, so that no cinders can escape. Horses are found to be frightened mainly by the sight of a carriage apparently running of itself, by violent puffs of smoke or steam (not the mere escape of steam at the chimney), and by rapidly moving gear. These causes can be removed to a great extent, if not entirely, by boxing up the gear, by placing an air vessel in the exhaust pipe, and by turning the escape from the cylinders and safety valves into the con-

* *Vide* Minutes of Proceedings Inst. C.E., Vol. lxi., p. 369: "Van Locomotive."

denser, and that from the injector into the tank.

Leading Dimensions.—The engines are taken to weigh about 90 lbs. per square foot of heating surface; it being assumed that they are built on the Krauss system, and that the grate surface and tank capacity will be varied according to the gauge. The useful steam generated is taken at 5 lbs. per square foot of heating surface per hour, with a pressure of 150 lbs. The latest cut-off, on the steepest gradient, should not exceed 0.4 of the stroke, which gives mean pressure = 97 lbs., and work done per pound of steam = 102,000 foot-lbs. The adhesion co-efficient, with sanded rails, may be taken at 0.15; whence, assuming that the engine may lose 11 per cent. of its full weight, through consumption of fuel and water, the tractive force may be taken as 0.133 of the full weight. The wheel diameter for standard gauge may be taken as 3 feet 3 inches, the same as for the carriages, which, at 18 miles an hour, the maximum speed, gives 2.8 revolutions per second. For the narrow gauges the speed should not exceed 12 to 15 miles an hour, and the diameter of the wheels may be from 2 feet to 2 feet 8 inches. The length of stroke should be about half the wheel diameter. The cylinder diameter may be calculated (for metric measures) from the following equation:

$$d_1 = 0.011 \times \frac{\text{Tractive force}}{3.4}$$, where 0.011 is Koch's value for the co-efficient of machine friction in locomotives. The grate surface should be as large as possible, say $\frac{1}{50}$ heating surface for standard gauge, $\frac{1}{60}$ for meter gauge. The tank may hold 3½ cubic feet, and the bunkers 1.1 cubic feet, per ton of engine weight. The above and other leading particulars are combined in the following table:

TABLE I.—LEADING DIMENSIONS.

Gauge	Standard.		Meter.		¾ Meter.	
Number of wheels	4	6	4	6	4	6
Full weight.....tons.	18	27	15	22½	7½	11.3
Heating surface.....sq. feet.	430	646	355	538	177	269
Grate..... " .	7.6	12.9	6.0	9.0	3.0	4.5
Pressure .....lbs. per sq. inch.	150	150	150	150	150	150
Diameter of wheels.....inches.	39	39	31.5	31.5	24	24
" " cylinder..... " .	11.0	13.4	9.9	12.2	7.1	8.7
Stroke " " ..... " .	19.5	19.5	15.7	15.7	12.0	12.0
Capacity of tank.....cubic yards.	2.9	4.2	2.15	3.25	0.98	1.45
" " bunkers..... " .	0.7	1.0	0 6	0.9	0.3	0.45
Wheel-base.....feet.	8.2	9.8	6.6	8.2	5.25	6.6
Tractive force (without friction)...tons.	2.4	3.6	2.0	3.0	1.0	1.5

Performance of the Engines on various Gradients.—The various figures assumed above give an effective power for the engine of about 6.3 HP. per ton weight. The tractive force per ton weight, including friction, will be about 321 lbs., whence it is calculated that the speed required to develop the maximum tractive force is 7 miles an hour; and this should therefore be taken as the speed on the steepest gradient of the line. On this assumption the maximum haulage load on various gradients, exclusive of the engine, is given by the table on next page.

Working.—The cost of fuel and repairs may be greatly diminished on light railways, by keeping the speeds on gradients below the steepest at a proper limit; the principle being that the generation of steam should never be faster than it is on the steepest gradient. If this gradient is greater than 1 in 100, the evaporation, with lighter gradients and higher speed, will remain about the same. If it is less than 1 in 100, the evaporation diminishes rapidly on lighter gradients, and the speed must therefore be regulated by some positive limit, which in Germany is 18 miles an hour.

The gross consumption of water per hour may be taken at 6.5 lbs. per square foot of heating surface, or 0.075 of the weight of the engine. The total weight of water in the tank may be taken at 0 1 of the engine weight; and, assuming

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TABLE II.

Gauge.	Weight of Engine.	Tractive force.	Maximum weight (tons) of Train on gradient of									
			1 in 200	1 in 150	1 in 100	1 in 80	1 in 60	1 in 50	1 in 40	1 in 30	1 in 25	1 in 20
	Tons.	Tons.										
Standard	18.0	2.4	320	255	180	146	110	91	71	50	39	28
	27.0	3.6	475	385	270	220	166	136	116	75	59	42
Meter...	15.0	2.0	265	213	150	122	92	75	59	42	33	24
	22.5	3.0	400	320	225	183	128	114	89	63	49	35
½ Meter.	7.5	1.0	132	107	75	61	46	38	30	21	16	12
	11.3	1.5	200	160	113	92	70	57	45	31	25	18

that one-quarter of this should be reserved for emergencies, it would follow that the watering stations should be one hour's distance apart. But this assumes that the engine will always be exerting its maximum power, and, taking this and other circumstances into consideration, the watering stations may be placed at about double the above distance. They should be of the simplest character, generally consisting of a well from which water may be drawn by an ejector or pulsometer, worked by the engine. It is only at the engine sheds that a tank is necessary, and this may be filled by means of the steam left in the engines when they come in. As to the distance between the coaling stations, assuming that each pound of coal will evaporate 8 lbs. of water, and that the capacity of the bunkers is only one-quarter that of the tank, it will follow that this should be double the distance between the watering stations. — *Glaser's Annalen.*

ESCAPE FROM A SECOND TAY BRIDGE CATASTROPHE.

From "The Builder."

THE banks of the Solway are the birthplace and the home of legend. The region is resonant with ballad. The magic of nature seems to have prepared a scene for the magic of romance. The craggy heights of Criffel look down on a noble estuary. The tourist who views the spot from the lofty top of Skidaw sees fertile plains divided into numerous enclosures that look like gardens, while the river, when the tide is in ebb, traces a fivefold line to the sea. On either side are brown and glittering sands. Then come two converging lines of turbid water; and in the center is a narrow streak glittering like silver. Nor are the charms of the natural scene all that add interest to the spot. Over the broad expanse of sand the sea sometimes comes up in flood as fast as a horse can trot. And in the little fishing village of Allonby, when stormy weather is at hand, the hills of the Isle of Man may often be distinctly seen, although such vision is but the effect of mirage. High country intervenes between the shore of the Solway and the western coast of the Irish Channel, so that the appearance of this natural portent is in itself a phenomenon fitted to dispose the mind to the ready acceptation of the marvelous. Nowhere in the British islands, except from the hills to the east of Cork, have we ever witnessed the rare deception of the *fata morgana* so plainly as on the banks of the Solway.

On the last day of January, in the present year, the Solway very narrowly escaped becoming the scene of a calamity that would have been without a precedent in all the ghostly tales of border lore. It was due to the simple, old-fashioned, often derided precaution of the night watchman that the evil fame of

the Solway viaduct has not rivaled the discredit of its sister structure across the Tay—sister, that is to say, in object and in fate, albeit presenting little family likeness in appearance; indeed, the very opposite principles have been adopted for crossing the two estuaries. In the Tay bridge the central girders spanned openings of 245 feet wide. In the Solway bridge the spans are only 30 feet. Thus eight piers have to be reared in the latter structure, for one on the former. The height and cost of the girders, which, on the Tay bridge were 27 feet deep, are proportionately diminished. The Solway bridge would have felt almost nothing of the storm which blew down the Tay bridge. But the Tay bridge would have been but little affected (or might have been but little affected) by the islands of floating ice that crushed so many of the light and frequent piers of the Solway viaduct.

The Solway bridge has been open for traffic for above twelve years; it ought, therefore, to be all the more remembered, to the credit of the officials of the railway company, that on the setting in of the thaw the bridge was carefully watched. The accounts at present received do not mention when the traffic over bridge was suspended. It is, however, evident that no trains were allowed to attempt to cross the Solway on the night of the 31st, for had such been the case, the catastrophe of the Tay bridge would have been exactly repeated. So loud were the crashes of the ice against the piers of the bridge in the course of the night, that it was feared that serious damage had occurred. By daybreak it was seen that five of the piers, each consisting of five hollow columns, of 12 inches diameter, had been destroyed, although the continuous line of girder and platform was so well bolted together as to be unbroken. Some of the other piers had been damaged; one, indeed, had been damaged on the 29th. On the night of the 31st further damage was done to the structure by the masses of ice borne by the high tides, and on the morning of the 1st instant a complete gap was made, to the width of 90 feet. This is about 600 yards from the Scottish or northern end of the viaduct. Nearer the Cumberland coast is a yet wider breach, extending, it is said, to the width of nine of the 30 feet spans. The bridge was veiled in a dense fog through the night, and the damage done was not fully ascertained on the morning of the 1st.

The length of the viaduct is stated at 1,960 yards, and as the waterway is also given as 5,666 feet, only the width of 12 inches is allowed for each pier. In fact, the supports of the girders appear to have been simple rows of iron columns, of 12 inches diameter, five in a row. These are described as sunk into the bed of the Firth to an average depth of 16 feet, the height being from 35 feet to 40 feet. If this be correct, it would seem difficult to design a mode of supporting a river bridge which would form a more effectual ice trap. A great number of feeble columns, planted at the narrow intervals of 30 feet, afford a positive invitation to danger from ice or floating wreck. The only things to cause surprise are: How could the Board of Trade have sanctioned such a structure? and, How is it that it has stood so long?

It is curious that in the mode of crossing these two important estuaries such opposite ideas of economical structure should have been carried out. No doubt the height of the rails above the sea had much to do with this, as the Tay bridge, if the accounts are accurate, was three or four times as high as the Solway bridge—as high, that is to say, measured to the level soffit; for the depth of the 245-feet girder was, of course, much more than that of the 30-foot girder. But if the height were fourfold, it is hardly a justification for an eightfold difference in the span. In point of fact, spans of 30 feet form almost the cheapest possible arrangement for a long viaduct. Where the expenses of obtaining foundations are great, this circumstance has to form the basis of a comparative calculation. In other respects, while the cost per foot super. of the platform, rails, &c., is the same for all spans, the cost of the main girders is almost directly as the squares of the spans. In the Solway bridge the simple and inexpensive character of the piers was such as to allow of the reduction of the span to the narrow width before stated. But the economy was a pitiable one which dotted the bed of the Solway with rows of feeble columns, which

any hard winter menaced with overthrow.

It is a remarkable circumstance that, in two cases presenting so close a parallel, the pursuit of economy has led to the exposing of the several structures to the destructive action of two natural forces against each of which the engineer had ample warning to provide. For what may be called a new danger in the history of bridge building, the engineer of each viaduct indeed provided. The Roman engineers, and the French and Italian architects, who reared the great bridges, viaducts, and aqueducts which form some of the marvels of European architecture, never contemplated having to design structures that could support trains of carriages of hundreds of tons weight, whirling along at a speed of from ten to fifty miles an hour. The weight that could come on a Roman bridge was comparatively small. The effect of wind pressure, even in such cases as the Pont de Gard, or the lofty Alcantara aqueduct, was not formidable against the weight of the solid masonry of piers and arches. Of the three elements of overthrow against which the old bridge builders had to provide, viz., moving weight, pressure of storm, and shocks from floods or from floating bodies borne down by floods, no doubt by far the greatest amount of attention was given to this last-named risk. In Old London Bridge, as we have mentioned in another place, there were 10 feet of pier to 7 feet of arch. When the engineer attempted to cross a deep estuary by gigantic strides, he forgot how great a destructible surface he exposed to the fury of the wind. On the other hand, when he attempted the same task by short and numerous steps, and thus provided in the most economical way for the support of moving weight, and produced a structure that could defy the wind, he forgot how liable were his numerous and slight supports to be swept away by ice, or by any floating matter dashed against them by tide or by current.

It is not to the credit of our practical architectural knowledge that we find, on the two opposite coasts of Britain, one bridge builder falling into Charybdis, while the other falls into Scylla. Economy is a great point for the architect t study. But it must be a wise economy. The first oversight committed by the great bridge builders of the railway times was that these structures were insufficient to bear the weight of their own thrust, or the weight of their own material, combined with that of a passing train. It ought to lead us to view other errors with much consideration, to reflect that two of the first engineers that our country produced had to learn the imperfections of formulæ on which, together with their brethren, they relied, by failure. Mr. Brunel's Maidenhead bridge fell down by its own weight when the centers were struck. Mr. Robert Stephenson's Dee bridge broke down with the first train that came on it after it had been covered with a coating of gravel. So that when we add to these the Tay bridge, fairly torn from its piers by a hurricane, and the Solway bridge, with its legs knocked from under it by floating ice, we have practical warning of the force of the three chief different dangers with which, as before said, the bridge builder has to contend. May we not hope that the fourth catastrophe may cause all concerned to put to themselves the question whether, in looking to cheapness, they have provided against every source of danger? And we must add that a special warning has been given to look to the soundness of all great viaducts, more especially those made of iron. The loss incurred by the destruction of the Solway bridge is very heavy. Watchfulness prevented it from being fatal. We should like to be convinced that there are no other cases in which very probable causes of danger have been overlooked in construction, or in which rust, vibration, or molecular change has not been allowed to make silent inroads on the margin of stability.

The manufacture of tin plates originated in Northern Germany, and as a trade had existed many years in Bohemia. From Bohemia, in 1620, it was carried into Saxony by the Duke of Saxony, and from Saxony the secret came to England in 1670 and was tried at Pontypool, but was given up and neglected until 1720, up to which date our ancestors had imported tin plates from Hamburg, though tin had gone from our shores to other countries. —*English Papers.*

EXPERIMENTS ON THE ACTION OF FATS AND MINERAL LUBRICANTS ON IRON, IN THE PRESENCE OF HIGH-PRESSURE STEAM.

From "Abstracts" of the Institution of Civil Engineers.

It is well known that steam of high temperature decomposes natural fats, and causes free acids to separate from them. When used as lubricants, in cylinders employing high-pressure steam, the resulting acids corrode the metal surfaces with which they come in contact. With steam of very high pressure, this takes place with great rapidity; with steam of medium pressure it continues, though to a less degree; but it goes on also even in the damp atmosphere, as is proved by fats turning rancid when exposed to the air. In engines provided with surface condensers, the result may be serious injury to the boilers; for the fats carried away from the cylinders with the exhaust steam, are returned to the boilers in the feed-water and are there decomposed. The continuous action of hot steam causes also the generation of volatile acids, which leave the boiler with the steam, and injuriously affect steam pipes and cylinders. In this way the speedy destruction of boilers fed from surface condensers is generally accounted for. Some persons attribute this destruction, to a certain extent, to the use of distilled feed-water. In consequence of all this, mineral oils, which consist chiefly of hydro-carbons, and which do not suffer decomposition at the ordinary temperature of steam boilers, have come into use, although as lubricants they are far from efficient at high temperatures. One circumstance should, however, be mentioned, which somewhat diminishes the usefulness of mineral oils, viz., at high temperatures mineral oils adhere to the sides of the cylinders less than water does, and consequently, when steam is shut off, the condensed water rusts the surfaces more than it would do, were animal fats used. The following experiments were all made in consequence of the remarkable results given by the following analysis of the sediment deposited in the surface condenser,

—	I. Deposit from Condenser.	II. Deposit from Cylinder.	III. Deposit from Boiler.
	Per cent.	Per cent.	Per ct.
Water	10.59	0.23	0.88
Mineral oil	36.29	18.43	1.50
Fatty acids	24.19	2.70	0.58
Neutral fats		2.14	0.12
Copper (In the metallic state)	1.78	2.11	—
Lead (In the metallic state)	1.08	0.50	—
Zinc (In the metallic state)	0.30	0.40	—
Iron (In the metallic state)	7.37	21.44	—
Oxide of iron	16.0	46.58	74.26
Peroxide of iron	—	—	14.68
Gypsum	0.32	trace	5.34
Salt, common	0.74	trace	1.93
Organic dirt	2.98	2.58	0.58
Inorganic dirt	1.79	2.89	trace

cylinder, and boilers of a marine engine. The lubricants used were, first, tallow, and then, till the day of the experiments, mineral oil. The metal found in the deposit existed in the state of very fine dust, which preserved its metallic brightness perfectly. The iron was in such a minute state of subdivision that, after separation from the compound, it burnt spontaneously with a bright red heat on exposure to the air. These particles of metal were of course produced by the friction of the piston, etc., and it is a matter of special importance to observe that, in spite of their minute subdivision, and prolonged exposure to the oxidizing influence of water and steam of high temperature, they were, nevertheless, perfectly free from oxidation. Apparently the remains of the lubricants had preserved them; and hence the question arises—in opposition to the commonly received views—to what extent do these residues of the lubricants preserve metals from the oxidizing influence of water and steam?

To solve this question a strong copper boiler was made use of, connected by means of a pipe with a receiver, having

a screwed top. Into the receiver were placed small vessels, which contained the metal plates and the different lubricants to be experimented upon; so that any differences in the corrosion of the plates could only be ascribed to the action of the lubricant. The pressure in the boiler was maintained at from two to three atmospheres above the air pressure. The test-plates were accurately-weighed pieces of boiler plates, which, after the experiments, were thoroughly cleaned and again weighed. The difference in the weights gave the amount of iron lost by oxidation. The experiments were made with both sea and distilled water. The plates were half immersed in the water, their surfaces having been painted with the lubricating material, a little of which was also poured on the surface of the water. The following table gives the results:

No.	Length of Experiment. Days.	——	Weight of Plate in milligrammes. = 0.0154 grain.		Loss of weight in milligram'es.
			Before the Experiment.	After the Experiment.	
1	2	In sea water	32564.0	32519.0	45.0
2	2	" " with tallow	32386.0	32375.0	11.0
3	2	" " " mineral oil	29961.5	29954.5	7.0
4	6	" " (no lubricant)	32228.5	32050.0	178.5
5	6	" " with tallow	32198.5	32171.0	27.5
6	6	" " " mineral oil	29814.5	29796.0	18.5
7	6	In distilled water	31907.0	31867.0	40.0
8	6	" " " with tallow	32126.0	32115.0	11.0
9	6	" " " " mineral oil	29751.0	29734.0	17.0
10	6	" " " (no lubricant)	29693.5	29652.0	41.5
11	6	" " " with tallow	31775.5	31764.0	11.5
12	6	" " " " mineral oil	32066.0	32050.5	15.5

Experiments 1 to 6 prove that sea-water alone and its steam destroys iron more rapidly than when tallow and mineral oil are present. The tallow, when fresh, contained 0.4 per cent. free acid, and after six days' exposure to steam, 3.4 per cent. Experiments 7 to 9 prove the same thing with regard to distilled water, and prove also that distilled water is less harmful than salt water.

In experiments 10 to 12 the plates, which were before exposed to the pure distilled water, were now coated with the lubricant, and *vice versa*, but without altering the result.

The oft-observed fact, that boilers of engines provided with surface condensers have a very short life-time, must therefore be ascribed to some other effect of the lubricating material than the generation of acids, for it has been proved above that, in spite of the presence of acids, the lubricants tend to preserve the plates from rust.

The following reason is advanced by the author to account for the destruction of the boilers, no account being taken of the direct action of the acids. When the lubricants come into the boiler, and acids are formed, these latter, acting on the lime and other alcalic minerals in the feed water, form insoluble soaps, which are deposited on the sides and bottom of the boiler, furnaces, etc. Furthermore, the fatty acids, acting on the oxide of iron contained in the feed-water, or existing on the boiler-plates, form insoluble iron soap, which also is deposited in a similar manner. These soaps are non-conductors, and in consequence the plates which are covered by, and which are also exposed to the action of the fire, are overheated and rapidly destroyed. An illustration of this action may be obtained by boiling sea-water in a platinum basin, over a moderate steady flame. Under these circumstances the boiling proceeds quite quietly. Let now a few drops of an oil rich in acids be dropped on the water; after a few moments the

steady boiling ceases, and violent ebullition and foaming takes place. The bottom of the basin will be found to be covered with a thin layer of soap, which the water cannot touch.

The author carried out a series of experiments to determine the relative values of tallow and mineral oils as preservatives for iron, under conditions which obtain in boilers. The result was that the mineral oils proved incomparably the best. When tallow is used, the result is satisfactory for the first few days, but as the formation of acids steadily progresses, so the oxidation rapidly increases. As a result of his researches, the author recommends that, wherever the lubricating qualities of mineral oils suit the circumstances, they should be used with engines provided with surface condensers; but in the case of ordinary condensers, and non-condensing engines, tallow may be used without any ill effect, as it passes through the cylinder before there is time for acids to form, and consequently the metal surfaces are not exposed to any injurious action.

THE INJECTOR AS A MOTOR FOR HYDRAULIC LIFTS.

By Hr. OTHEGRAVEN.

From "Abstracts" of the Institution of Civil Engineers.

THE author remarks that the advantage of using hydraulic power for the lifting of heavy weights through short distances has long been recognized; but an important objection is the necessity of special plant (engines, pumps, accumulator, etc.) to generate the motive force. This plant, besides its cost, is often difficult to find room for; and if located in some corner of a large shop, the distance to which the pipes have to be carried is a serious drawback. In such pipes frost is often a danger, where they cannot readily be buried, and the fact that the need for such tools is often occasional only makes another difficulty. These objections are obviated by using the ordinary injector to supply the motive power. An injector in good working order will raise water to a pressure about 50 per cent. higher than the steam pressure by which it works. It is therefore only a question of the most convenient method of application. It may be sufficient in many cases to use the actual injector of a locomotive, connecting its outlet direct to the pressure cylinder; but since this connection takes time, it is better to have a portable injector fixed to a small water tank. This injector is connected by flexible tubing to the pressure cylinder at one end, and to the locomotive boiler at the other; the attachment to the latter being made at the opening of the overflow pipe of its own injector. The steam valve of the engine injector is then opened, and the delivery valve closed; the steam is therefore obliged to pass through the opening of the overflow pipe to the portable injector, and thence to the pressure cylinder. Using this arrangement, with a steam pressure of 150 lbs., and with a pressure cylinder of 0.7 meter diameter ($27\frac{1}{2}$ inches) one man can with ease lift and turn on a turntable a locomotive of 35 tons weight, using its own steam for the purpose. The water is at once let off, when required, by opening a cock. The method may also be applied for tipping coal wagons on wharves; the engine which shifts the wagons supplies the steam in this case, the making and breaking of the connection being so easy that no time is lost. Another arrangement consists of a portable pressure cylinder slung from an elevated beam, and is used for lifting wheels and axles out of a sunken road, which has been done by this means in one-ninth of the time it formerly occupied. Yet another is a portable cylinder of 420 millimeters, diameter ($16\frac{1}{2}$ inches), taking the place of a hydraulic jack in cases of derailment, etc. In all these cases the principle is the same, viz., to use the steam of the nearest available boiler (especially a locomotive) to generate the required pressure by means of an injector just as it is wanted, instead of fixed pumps and accumulators to maintain the pressure continuously.—*Organ fur die Fortschritte des Eisenbahnwesens.*

DEEP-SEA INVESTIGATION, AND THE APPARATUS EMPLOYED IN IT.

By J. Y. BUCHANAN, F. R. S. E., F. C. S.

From the "Journal of the Society of Arts."

DEEP-sea investigation, in the sense of exploring the surface of the ocean with the view of discovering new lands, and so determining the boundaries of the sea, has, in all ages, commanded the attention of the more civilized races of mankind, and the most adventurous of their members have ever engaged with enthusiasm in its pursuit. It is probable that the first voyages were undertaken, less with a view to satisfy curiosity, than to render traveling from place to place more expeditious and less irksome. It was not until the mariner's compass had been introduced into Europe, in the 12th century, that long voyages, out of sight of land, could be undertaken; although the enterprise of the Mediterranean mariners enabled them to take their ships as far as Britain without any such aid; and no one who is at all acquainted with practical navigation, will deny the difficulty and the danger of the undertaking. The adoption of the compass as a standard of direction, and the immense amount of valuable property which was consequently risked on the faith of its infallibility, raised a strong interest in the study of the behavior of the magnetic needle in different localities, especially at sea, resulting in the discovery and investigation of the magnetic variation which, consequently, became a recognized phenomenon, to be taken into account in all questions affecting a ship's reckoning. During his voyage, which ended in the discovery of America, Columbus crossed and determined the position of a line of "no variation" somewhat west of the Azores. This line was, by Papal decree, made the boundary between the rival kingdoms of Portugal and Castille, and thus, to the determination of its position, was given a factitious importance which was the indirect cause of much valuable geographical discovery. The first voyages for scientific purposes were thus undertaken for determining the magnetic constants at different places on the ocean, and as these are subject to continual variations, their re-determination from time to time is likely to furnish, in the future, a motive for frequent maritime expeditions.

It was in connection with the investigation of magnetic phenomena that an exceedingly convenient method of graphically representing the relation between isolated observations, received its first extension. In an ordinary map or chart, one of the principal features is the coast line. This line represents the most probable direction of the intersection of the sea surface with the land surface, as deduced from observations at isolated points. With greater detail in the survey, the height of points inland above the sea is determined, from which profiles are drawn, and points of equal height on these profiles are connected, and their projections on the sea surface are entered in the map as lines of equal height above the sea, generally called contour lines. When the depth of the land below the sea is determined, the same method of graphic representation is adopted. In a chart, however, all the original determinations of depth are entered, while in the map the general configuration of the country is represented as deduced from the individual observations. Similarly, in rendering the results obtained by the magnetic observer conveniently and intelligibly accessible to the public, and especially to the navigator, the results of the determinations of variation at the different localities are entered in a chart, and points of equal variation are connected by lines drawn at convenient intervals, as from degree to degree, or every five degrees. Here the case of sea and land charts is reversed. At sea the magnetic constants vary gradually, and nowhere abruptly, consequently a chart of magnetic contours of moderately recent date supplies all the wants of navigation. It is other-

wise, however, on land, especially in volcanic countries, or those consisting largely of igneous rocks. An almost constant constituent of these rocks is magnetic oxide of iron or loadstone, and the proportion in which it is present in rocks, immediately adjacent to one another, often varies within very wide limits. The consequence is, that the needle points in different directions at localities close to each other, so that a survey of such a country would differ very materially, according as the bearings were dependent on solar or magnetic observations.

The employment of contour lines to represent the results first of geodetical, then of magnetic, observations, was extended by Humboldt to the representation of temperature phenomena. They have since been largely used to represent the distribution of other qualities, such as density of sea water, and of plants, animals, &c.

Important, however, as is the investigation of magnetic phenomena at sea, it is not my intention to refer further to it to-night; it is enough to have pointed out that the interest which it possessed for navigation was the moving cause of the fitting out of the earliest maritime scientific expeditions. Our concern is with the determination of the depth of the ocean, of the distribution of temperature of its waters, of the chemical and physical character of its waters, and of the ground at its bottom, and with the distribution of life in it.

The first problem of deep-sea investigation is to determine the extent of the ocean, its size, its volume. The superficial extent and limits are determined by the surveyor In order to map out the bottom of the sea, there is only one method, namely, the direct determination of the depth at as many places as possible.

When a ship is "in soundings," the depth is ascertained at frequent intervals by a "leadsman" stationed in some convenient place on the outside of the ship, whence he can throw forward the lead attached to the line which he carries in his hand. The ordinary hand lead line is from 20 to 25 fathoms long, and it is conventionally marked with bits of leather at 2, 3 and 10 fathoms, white bunting at 5 and 15, red bunting at 7 and 17, blue bunting at 13, and with two knots at 20 fathoms. The lead is a long, finely tapered block, of generally 14 lbs. weight; it has a recess at the thick end, and is perforated at the other end for the reception of the line. This instrument is chiefly used while the ship is in motion. The man entrusted with the duty swings the lead backwards and forwards, and even completely round a vertical circle, in order to generate the requisite momentum to carry the lead well in advance of the ship before it touches the water. It then sinks rapidly, whilst the leadsman's position is advancing to the spot where the lead touched the water. When the line has thus been brought up and down, the depth is ascertained by observation of the marks on the line It is obvious that by this primitive, but effective, method of sounding, the limiting depth which can be so ascertained depends chiefly on the speed of the vessel, and in a less degree on the skill and strength of the leadsman. Under ordinary circumstances, the method is effective in depths up to twelve or fifteen fathoms, and this degree of efficiency suffices for most purposes.

Occasionally, however, it is advisable to sound in greater depths, without the ship being necessarily stationary. The simplest method of doing so is to reduce as much as possible the ship's way, and having carried the line well forward, to leave it there, and give it line as it sinks. Here the depth and the speed of the vessel should be so proportioned, that the lead reaches the bottom before the ship has passed completely over it. With care, very accurate soundings can be obtained in this way, but the depth must not be much above thirty or forty fathoms.

When the object is to sound in ocean water, where we must be prepared to meet with depths of two or three thousand fathoms, it is essential that the vessel be kept stationary, and if hemp line be used, much heavier weights must be employed. Sounding in great depths is one of the most important operations connected with deep-sea investigations, and it is only within the last thirty years that it has received any very great attention. Probably the first attempt at deep-sea sounding was made by Captain Constantine John Phipps, during his

Arctic voyage, in the year 1773, when he was accompanied by Dr. Irving, who made a number of very valuable determinations of the temperature of the sea water at different depths, besides fitting the vessel with one of the earliest stills, which worked well, and supplied the crew with fresh water during the whole cruise. Phipps' deepest sounding appears to have been 683 fathoms. For this purpose, all the lead line in the ship was used, and a lead weighing 150 lbs., which appeared to have sunk about ten feet into the mud, a soft blue clay. With this was sent down a water bottle, of Dr. Irving's construction, and the water brought up had a pressure of 40° Fahr., that of the surface being 55° Fahr. The density of the water was also measured, and Cavendish's self-registering thermometers were used. So that, at this early date, the methods and objects of deep-sea investigations were perfectly understood. What prevented much work being done was chiefly the want of steam. But little advance was made in this branch of research until after the termination of the French war. In 1818, Captain John Ross made his well-known voyage of discovery to the Arctic seas, in H.M. ss. "Isabella" and "Alexander." During this voyage, he paid great attention to deep-sea investigation, and invented, and had constructed, one of the earliest satisfactory instruments for bringing up a considerable quantity of the bottom mud in deep water. He, himself, gives the following account of his instrument and its performances, in the appendix to the account of the voyage:

"This instrument was invented by me on board his Majesty's ship "Isabella" in the early part of our voyage to the Arctic Regions. Many fruitless attempts had been made to procure substances from the bottom of the sea in deep water, by the instruments with which we were supplied, and I had an opportunity of observing the reasons of this failure, which led to the discovery of that which I am about to describe, and which, in almost every instance, completely succeeded in accomplishing that desirable object, of bringing up substances of any description, in considerable quantity, from any depth; but it has also been found to preserve the temperature of any substances, if they are soft, until it can be measured by the thermometer, and by that means the temperature of the earth can be nearly ascertained at any fathomable depth. In Melville Bay, on the 1st of August, it brought up from four hundred and twenty fathoms some soft mud, into which the thermometer was immediately immersed, and it gave 29½°. At the same time, the self-registering thermometer, at the depth of two hundred and ten fathoms, gave the same temperature. In Prince Regent's Bay, in four hundred and fifty-five fathoms, it gave the same temperature. In the entrance of Lancaster Sound, at the depth of six hundred and seventy-four fathoms, the temperature of the mud was also found to be 29¼°; and at the highest part of that inlet in which we sounded, the mud was found to be, in six hundred and fifty fathoms, 29°.

"On the 6th of September, in latitude 72° 23′ N., and longitude 73° 07½ W., we sounded in 1,050 fathoms, from which depth the instrument brought up 6 lbs. of very soft mud. The next day being quite calm, we tried the temperature of the sea at five, six, seven, eight hundred, and a thousand fathoms, and found its temperature decrease from 35 gradually to the same temperature as the instrument gave it, which was 28¾. Although the instrument may not bring up the mud at the exact temperature of that at the bottom, it may be supposed that it cannot have suffered much alteration, from its agreeing so nearly with the self-registering thermometer, and that, if it has altered, it must be to increase the degree of temperature; hence, it may always be inferred that the mud at the bottom is not of a higher temperature than that brought up by the instrument. The reasons for so little alteration taking place is the closeness with which the instrument confines the mud, which is such as not to allow even the water to escape. If the instrument strikes among stones which are small enough to get between the forceps, it will bring up as many as are enclosed in them; in one instance, it brought up a stone (which weighed two pounds and a half) from 300 fathoms, and, in another, it struck a rock and cut a piece out, which it brought up from 216 fathoms. The instrument was made from the model by the ship's

armorer, and succeeded on the first trial.

"To use the deep-sea clamms, it is necessary to be provided with whale lines, such as are used by the Greenland and South Sea ships, which are two and a-half inches in circumference, made of the best hemp, and very pliable and easily coiled; the lines ought to be spliced together, and faked or coiled, so as to run quite clear on the fore part of the ship's decks. In very deep water it is necessary that it should be calm, or nearly so, to be certain that soundings are obtained in 500 fathoms; but, in a light breeze, the instrument may be hung to a boat and towed in the direction of the ship's drift, and if there is any wind it is best to lower all the sails down. An outrigger, fitted with a block, should be fixed in the weather quarter, through which the line ought to be rove and bent to the instrument, when it ought to be lowered until it is a fathom below the surface, and then let go. The instruments and lines may, however, be made for different depths, and used accordingly. For the North Sea I would recommend one of fifty pounds."'

The cast iron sinker of the one actually used by Captain Ross was a long, hollow, parallelopiped, weighing one hundred weight.

About the same time as Sir John Ross was prosecuting his voyages on behalf of the Government, Scoresby, in pursuit of his trade as a whaler, was collecting most valuable information. Of all the navigators who have combined with the due discharge of their duties as sailors the scientific investigation of the conditions of the ocean, the younger Scoresby is certainly the one most imbued with the spirit of the philosopher. The problems to be solved seem to present themselves at once to his mind divested of all irrelevant matter, and he attacks them directly and successfully. In sounding at great depths, for instance, he at once recognizes that when the ordinary deep sea line and lead are used, the increasing weight of line, in proportion as more of it is required, renders less certain the determination of the moment when bottom is reached. He determines the density of the water with a thermometer with large bulb and narrow stem, and he gives a table for correcting observed specific gravities for temperature, which shows that he knew that sea water did not attain a maximum of density at the same temperature as distilled water. The following passage from his "Arctic Voyage" will show how thoroughly he knew the nature of the work which he had taken up:

"The difficulty of getting satisfactory soundings at great depths arises, principally, from the uncertain intimation given when the lead strikes the bottom. This uncertainty is increased by using a thick line; for if a lead of a hundred pounds were used, the rope attached to it would require to be so thick that, at the depth of six or eight hundred fathoms, the weight of the line, even in water, would be so many times greater than that of the lead, that scarcely any effect could be observed when it should reach the bottom. Hence, I always prefer a light lead and a very small line. With a lead of 20 pounds I have sounded in above 1,000 fathoms, and felt assured that if it had struck the bottom I should have observed it, for the whole of the line in use was not above twice as heavy as the lead; so that the diminution of one-third of the weight would have been very observable. But with a heavy lead and thick line, where the strength of several men is requisite to haul it up, there can be no evidence, without the test of weighing, of any trifling alteration in the strain of weight. Hence, if the lead is found to have been at the bottom, there can be no assurance that a quantity of the line, as well as the lead, has not also been on the ground. To a 20 lb. or 28 lb. lead I generally attach 200 or 300 fathoms of common log line, where there is no valuable apparatus along with it, and to this a small lead line, and finish with a deep sea line, thus increasing the line in thickness with the increase of weight to be supported; and having the whole of such a weight that the line can be held in the hand, and the least stoppage made perceptible."

After showing how, from observation of the whale fishing, he had often been able to draw correct conclusions as to the depths of water, seeing the amount of line which they would take out when running perpendicularly downwards, he relates the following story from the log-

book of his father, who was also a whaler:

"At great depths, the effects of the pressure of the sea is not a little curious. My father met with the following singular instance, in the year 1749, which I have taken from his logbook. On the 31st of May, the chief mate of the "Henrietta," of Whitby, the ship my father then commanded, struck a whale, which 'ran' all the lines out of the boat before assistance arrived, and then dragged the boat under water, the men meanwhile escaping to a piece of ice. When the fish returned to the surface to 'blow' it was struck a second time, and soon afterwards killed. The moment it expired it began to sink, which, not being a usual circumstance, excited some surprise. My father, who was himself assisting at the capture, observing the circumstance, seized a grapnel, fastened a rope to it, threw it over the tail of the fish, and fortunately hooked it. It continued to sink, but the line being held fast in the boat, at length stopped it, though not until the 'strain' was such that the boat was in danger of sinking. The 'bight' or loop of a rope being then passed round the fish, and allowed to drop below it, inclosed the line belonging to the sunken boat, which was found to be the cause of the phenomenon observed. Immediately the harpoon slipped out of the whale, and was, with the line and boat attached to it, on the point of being lost, when it was luckily caught by the encompassing rope. The fish being then released from the weight of the line and boat, rose to the surface; and the strain was transferred to the boat connected with the disengaged harpoon. My father, imagining that the sunken boat was entangled among rocks at the bottom of the sea, and that the action of a current on the line produced the extraordinary stress, proceeded himself to assist in hauling up the boat. The strain upon the line he estimated at no less than three-fourths of a ton, the utmost power of twenty-five men being requisite to overcome the weight. The laborious operation of hauling the line in occupied several hours, the weight continuing nearly the same throughout. The sunken boat, which before the accident would have been buoyant when full of water, when it came to the surface required a boat at each end to keep it from sinking. When it was hoisted into the ship, the paint came off the wood in large sheets, and the planks, which were of wainscot, were as completely soaked in every pore as if they had lain at the bottom of the sea since the Flood. A wooden apparatus that accompanied the boat in its progress through the deep, consisting chiefly of a piece of thick deal, about fifteen inches square, happened to fall overboard, and though it originally consisted of the lightest fir, sunk in the water like a stone. The boat was rendered useless; even the wood of which it was built, on being offered to the cook as fuel, was tried and rejected as incombustible."

The incident is exceedingly interesting, as being, perhaps, the first occasion on which the effect of the enormous pressure produced by a column of water was directly observed. It will be observed that the wood, though painted, got completely water-logged, while the whale, which must have penetrated to nearly the same depths, retained its buoyancy.

The plan introduced by the Americans, of using fine twine and a heavy weight, sacrificing both at every sounding, was one which, with a little elaboration, could have been made to give very accurate measurements of depth. And, indeed, when it was found that ordinary observation or feeling did not suffice to indicate when the shot had reached the bottom, the practice of observing the rate at which successive equal lengths of the line passed out, which has since been so useful, was introduced. It is worthy of remark that, at this early date (about 1850) iron wire was used instead of twine, by Lieutenant Walsh, of the U. S. schooner "Taney."

When telegraphic enterprise began to develop itself, deep-sea sounding became of great practical importance, and, since the date of the first Atlantic cable, it has been carried on both by governments and commercial companies, with all the energy produced by prospective money making. For the telegraphic engineer, however, it was not enough to know the depth of the water; it was of almost equal importance for him to know the nature of the ground on which his cable was to lie. The invention, in 1854, by passed Midshipman Brooke, of the U. S.

Navy, of a contrivance to detach the weight used to carry down the sounding line, while it enabled a specimen of the bottom to be brought up, was of great importance in rendering easier and more accurate the survey of the ocean bed. Brooke's sounding apparatus consisted of a cannon ball, with a hole drilled through it. Through this hole passed a straight rod, fitted at its upper end with peculiar disengaging hooks. The weight was slung to these hooks by means of a wire, which passed from a ring, which was slipped over the rod under the weight, up on each side of the cannon ball to the hooks. The sounding line was attached to eyes in these hooks, and as long as the lower end of this rod was not resting on anything, the weight was kept securely in its place, and available for taking out the sounding line. As soon, however, as bottom was reached, and this rod came to be supported on its lower end, the hooks at the upper end fell forward, and allowed the wire to disengage itself. The weight was thus released, and, on the line being pulled up, the rod came away through the perforation of the shot, and brought with it specimens of the mud in small quill tubes fitted in a recess in the lower end of the rod. The principal object which Brooke had in view was to disengage his weight, and his contrivance for doing so is excellent, the moment the end of the rod touches bottom, the weight slips off. In order, however, to gain the greatest possible amount of information from a deep-sea sounding, it is advisable to arrange so that the tube, which is now used in similar machines instead of a rod, should penetrate the ground as far as possible. This is attained by so arranging the apparatus that the weight does not detach at the moment of striking bottom, but only when hauling in is begun. This condition is fulfilled in the instrument used in H. M. S. "Bulldog," by Sir Leopold M'Clintock, in the year 1860. It is a modification of Sir John Ross's "deep-sea clamm," in which the weight presses the clamm into the ground, until, on pulling in the line, it is thrown off and left at the bottom. This instrument brings up a specimen of what is at the surface of the ground, but does not give a sample of what is below.

The "Fitzgerald" sounding machine was used in the expedition in H.M.S. "Lightning," in the summer of 1868, when it gave satisfaction. It was tried on board the U.S.S. "Tuscarora," and Commodore Belknap reports unfavorably of it. From its irregular form, it offers considerable resistance during descent, and in coming up gets the line full of kinks.

At the latter end of 1868, Captain Shortland was ordered to make soundings between Bombay and Aden, and for this purpose he devised and constructed on board his ship, the "Hydra," a modification of Brooke's apparatus, which gave great satisfaction, and was afterwards used in the "Porcupine" and the "Challenger." The general arrangement is the same as in Brooke's apparatus; instead, however, of a rod, he has a brass tube, which passes through the center of the weight, which consists of one or more cylinders of cast iron. These weights are slung by a wire to a shallow hook, on the upper part of the rod, which surrounds the brass tube. The lower end of the brass tube carries a pair of buterfly valves, and in the middle of the tube are two conical valves opening upwards, between which a sample of the bottom water is secured, while a specimen of the mud is brought up in the lower segment of the tube. In later instruments, the tube was adapted only for the reception of the mud. When this instrument was used, the tube penetrated into the ground until the weights were supported on the bottom, when a steel spring at the upper end of the rod expanded, and threw the bight of the wire off the hook. The weights were thus released, and on hauling in the line, the tube alone was brought up. During the first year of the cruise of the "Challenger," this instrument was exclusively used, and it gave general satisfaction. The principal objection to it lay in the smallness of the samples of bottom which it brought up. This was due first to the narrowness of the tube, and also to the butterfly valves at the end. The object of these valves is to keep the samples from being washed out, but they also very materially obstruct the entrances. With a much larger tube, and a rightly ground valve at the top, better samples would have been obtained.

After the first year of the cruise, the "Hydra" machine was replaced by the "Bailey." This was an apparatus very much on the same lines, but differing from the "Hydra," in the size of tube, and the method of disengaging. The tube, which was of iron, was 5 feet long by 2½ inches wide, and weighed alone 25 lbs. The hook which carried the wire and weights formed part of a separate brass piece, which telescoped into the iron tube the moment it touched bottom, thus throwing oft the weights without utilizing them for pressing the tube further into the mud. The weight, however, of the tube alone was so considerable, that this was of little matter, and the "Bailey" usually brought up large samples of mud. It must, however, be remembered, that though the samples were large in quantity, they were principally from the superficial layer. In working with a tube of 2½ inches internal diameter, a substantial valve of some sort is necessary to prevent the samples falling out when the tube is being brought on board. Such a valve is always a great impediment to the entrance of the mud. It would, therefore, be of great importance to arrange the Bailey tube, so that the weight should be utilized in shoving it into the ground, and also that a greater length of it should protrude beyond the weight. In this way, samples of the mud below the superficial layer would be obtained, and the interest attaching to it is evident. Even with the "Bailey," as it is, we find in several places a red clay at the surface, with white mud below it.

In exploring the seas and lakes of the Highlands of Scotland, I have made extensive use of a form of sounding tube and lead, which I devised for the purpose, and which I have always found to act very well. Its construction is simple, being in effect nothing but a straight brass tube, of one inch diameter, carrying a brass shoulder about one foot from the lower end. A cylindrical leaden sinker of suitable weight is slipped over the upper end, and rests on the shoulder. This line is made fast to a metal eye at the top, and the part of the tube below the shoulder can be unscrewed, and the mud which has been brought up in it squeezed out by a plunger. I have tubes of various lengths, with sinkers of various weights, for work at different depths, and under different conditions. For work in inland lakes it is necessary that every thing should be as light as possible, in order to be suitable for land transport. I use a tube and sinker, weighing in all three pounds; while at sea, with the steam winch available, the sinker weighs generally 28 lbs. Where the bottom is soft mud, these tubes bury themselves in it, and bring up very considerable samples. The samples are also very satisfactory when the bottom is clay; when, however, the bottom is hard sand, or similarly resisting material, the tube impinges suddenly on it, and does not penetrate as deeply as might be wished. The effect is very much as if an attempt were to be made to make a spade penetrate the ground by a sudden blow, instead of a persistent shove. I have designed an arrangement which will enable the tube to exercise a gradual pressure on the bottom, and so to penetrate muds or sands, which offer considerable resistance. Instead of the weight resting on a metal shoulder, rigidly attached to the tube, I suspend it by strong india-rubber cords, from hooks near the top of the tube. When the tube strikes the bottom, the weight delivers its blow gradually through the stretching of the india rubber. I have had a tube of this kind constructed five feet long, and with a valve at the top. This valve at the top is to prevent the contents of the tube falling out by their own weight, when the apparatus has been taken out of the water, and is being brought on board. These tubes bring up samples of often very coarse sand, and Captain Tizard, who tried one last year in the surveying vessel "Knight Errant," found that in *globigerina* ooze it was washed out on the way out. I feel sure that, with the india rubber slings, the tube would penetrate through the layer of comparatively unbroken *foraminifera* on the surface, and plug itself at the bottom with the more finely comminuted and clayey substance which is usually found below. Where the object is to make soundings rapidly, and to get a small sample of the mud on the surface of the bottom (as in sounding for telegraph cables), a lead with a blunt end is used. This penetrates only a small way into the mud, and is easily

drawn out, bringing a sufficient sample in the axial tube. Mr. Gray, of the Silvertown Telegraph Works Company, showed me the sinkers used on board their ships. They weigh thirty pounds, and at the bottom of the tube is a very simple and ingenious valve, made of india rubber, which is pressed against the side of tube by the lead, while sinking, and expands, and closes the orifice sufficiently to prevent the sample being washed out on coming up.

I now proceed to consider the precautions to be observed in the actual use of these instruments.

On stopping the ship, "to make a station," the first operation is to determine the depth. For this purpose the ship, under steam, is brought head, or in some cases stern, to wind, and kept as nearly as possible stationary while the sounding is being effected. The method of sounding in deep water is essentially the same whether hemp line or wire is used. In both cases, it is necessary to load the end of the line with such a weight that, in the deepest water which may reasonably be expected, the velocity of descent shall not be diminished to an excessive extent by the friction of the increasing length of line in passing through the water. Twenty years before the "Challenger" sailed, wire had been used on isolated occasions by the Americans, but it was not until Sir William Thomson took it up, and, with characteristic energy, worked it out into a practical method, that it became really available. When the "Challenger" was fitted out, it was decided, and, I think, wisely decided, to use hemp line, which had already yielded valuable results, and the working of which, even at the greatest depths, was familiar to her captain and officers. During the three and a-half years of her expedition, the extension of telegraphic enterprise rendered rapid deep-sea sounding a necessity, and, in consequence, developed both the apparatus and the art. Now-a-days, our sailors are almost as familiar with the handling of wire as with that of rope, and no similar expedition would now start without being furnished with apparatus for using wire in deep sounding. At the same time, it would be equally improper to start without a sufficient supply of good hemp line, and the apparatus for working it. For we should never allow our affection for what is novel to blind us to the advantages of what is older fashioned. For many purposes wire must supersede hemp, because it does the work better and more expeditiously, but there are other departments of the work of deep-sea investigation which are better done with hemp. The great advantage of wire above hemp is that, for the same tensile strength, we have a line which passes through the water without developing any serious retarding force due to friction, whereas, with hemp line, the retardation so produced is very great. The saving in time and labor, due to the absence of this frictional retardation, is so great that there can be no question of choice between wire and hemp when it is required to sound in deep ocean water. To take an example, in water of 1,500 fathoms, a three-hundred-weight sinker, with the best hemp-sounding line, takes twenty minutes to reach the bottom; with wire, and a thirty-pound sinker, the sounding is completed in from twenty-five to thirty minutes.

Although, however, it is thus incomparably superior to hemp for deep sounding, it has disadvantages from which the hemp is free. Its greatest drawback springs from its liability to break. A hemp line may be bent and twisted in any way we please, without its strength being in any way affected; not so, however, with wire. During its whole lifetime it must never suffer a sharp bend, or twist, or nick; if it does, its strength is gone; and if the damaged part is not cut out an accident is sure to happen. Again, Sir William Thomson has always advocated the use of naked steel wire, which rusts easily when moistened with salt water. In order to preserve it, the wire, along with the reel, has to be kept in a tank of water rendered alkaline with soda or lime. This is an inconvenience; but my own experience leads me to the conclusion that there is no reason why galvanized steel wire should not be used, and I find that it keeps perfectly well without any preservative. The objection usually raised to galvanized wire is, that the process of galvanizing weakens it. This difficulty I got over by taking No. 20 galvanized instead of No. 22 naked, as recommended by Sir William Thomson. Where steam power is not

available for heaving up, the wire possesses a very great advantage, for it can be easily worked, even at very great depths, by hand. The U. S. ship "Tuscarora," which, in 1874, sounded out the route from San Francisco to Japan, and, in doing so, surveyed the deepest water in the world, did all her sounding by hand. As an instance of what can be done, I will quote from Captain Belknap's report, the work done on the two days, January 17th and 18th. Six soundings were made, all in water over 4,000 fathoms in depth; forty-two observations of the temperature at depths below the surface and 1,200 fathoms were made, and the current was observed at 10, 20, 30, 50, 100 and 200 fathoms below the surface. One of the soundings, the depths being 4,356 fathoms, occupied two hours and twenty-seven minutes, the descent occupying fifty-three, and the reeling in ninety minutes.

With steam power at hand—and without it, it would be folly to attempt deep-sea work—hemp line becomes preferable to wire, where the other branches of deep-sea work are being carried out, such as serial temperature observations, and the collection of water samples from different depths.

Deep-sea thermometers which have been carefully compared with a standard, and which have been used in many soundings, are instruments of very great value, and if lost cannot be replaced by the purchase of new ones. Hence, in making such observations, the conditions which we have chiefly to keep in view is the safety of our thermometers, while, for the completeness of our work, it is important that the temperature should be observed at as many different depths as possible. Now, as the chance of the hemp breaking is very small when compared with the wire, it is permissible to risk a great number of thermometers on it than on a thin wire. Therefore, to get same number of observations with the wire would require the operations of sinking and heaving-in to be repeated a greater number of times than with the hemp, and as a thermometer must be allowed a certain time to take the temperature of the water, it will be seen that for such work the wire is in the end no more expeditious than the hemp, and the use of it is attended with considerable risk of the loss of valuable instruments. I am quite convinced from my own experience, that for all work in depths up to 500 or 600 fathoms, hemp is better for all purposes, because a sinker can be used, which will make it descend nearly as quick as wire, and, with a steam winch, it can be brought up at nearly the same rate.

The wire has, of course, the advantage, that it stows in much smaller space than ordinary sounding line.

Finally, and to answer the question which is often put me, whether wire or hemp should be used in a ship's outfit, I would say take both, as they are both useful in their proper places. For determinining the depth, use wire; for detail work, with the thermometers and water bottles, use hemp. In this way your sounding will be done expeditiously, and you will not lose your instruments.

With regard to dredging, which forms a very important department of deep-sea investigation, there can be no doubt of the great superiority of wire over hemp rope. The advantage in point of rapidity of work, and of stowage space, is much greater than in the case of sounding. Here, again, we are indebted for a scientific instrument to the enterprise of telegrapic engineers, for if it had not been a necessity for them, it is not likely that we should now have had the very beautiful flexible steel-wire hawsers which are to be found in nearly every ship.

Steel-wire rope was first used for deep-sea dredging by Professor Agassiz, in the winter 1877–78, and he has continued to use it with great success. His rope "was one and one-eighth inches in circumference, and was composed of six strands laid round a tarred hemp heart. Each of the six strands was composed of seven galvanized steel wires of No. 19 American (No. 20 Birmingham) gauge. The ultimate strength of the rope was 8,750 lbs.; weight per fathom 1.14 lb. in air, and, approximately, 1 lb. in sea water; price, eight cents per foot."

In the summer of 1878, I fitted the steam yacht "Mallard" with a steel-wire dredging rope, for work in depths up to 200 fathoms. It consisted of five strands, arranged around a center of cotton, and each strand consisted of

seven steel wires (No. 24 B. W. G.) 0.023 inches in diameter. The diameter of this rope is 0.19 inches, and circumference 0.06 inches; its weight per fathom is 0.33 lb., and breaking strain 30 cwt. It was, unfortunately, not made of galvanized wire, and has now been in use for three seasons without being kept in any kind of preservative; and, although necessarily rusty, its worst fault is that, when in use, it is apt to stain the deck.

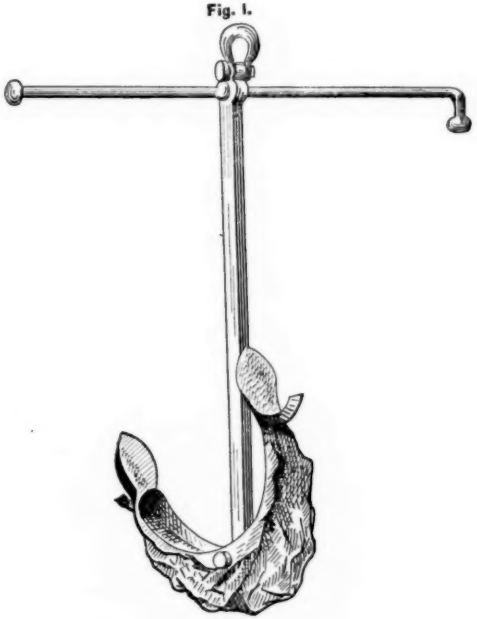
In deep water, Captain Sigsbee gives the following as safe work: Time per hundred fathoms, paying out and hauling back, three to five minutes, according to circumstances. He reports a good haul having been made in 800 fathoms in one hour and twenty minutes, including twenty-three minutes for dragging.

My object in furnishing myself with the wire rope was not to dredge, but to be able to anchor in the deepest water to be found on the west coast of Scotland, and thus facilitate the carrying out of physical and chemical observations on the water. In 1877, when I explored a large number of the Scottish lakes and sea lochs, I had found that, in a fresh-water lake, the vertical distribution of temperature is often very different in one place from what it is in another place not many hundred yards distant. The same was also found, though in less degree, in sea-water lakes. It became, therefore, of the utmost importance in investigating the conditions of temperature in the water, to be sure that the observations were really all made in one and the same place. It is impossible to keep a vessel stationary in one position by means of steam, unless, perhaps, in a land-locked bay, with a breeze blowing sufficiently strong to make the vessel drift faster than her lowest rate of steaming. It became, therefore, of the greatest importance to be able to anchor anywhere, and for this purpose the rope above described was furnished. In the season of 1878, I used a kedge anchor of ordinary form, and weighing 84 lbs. It was attached to the wire rope by means of about twelve fathoms of 2½ inch Manilla rope. Often a couple of furnace bars were strapped on to the Manilla at five and ten fathoms from the anchor, with a view to keep a curve on the line. This arrangement was found to work extremely well. Everything was prepared beforehand, and when the vessel was in position the anchor was let go, and the wire rope allowed to run rapidly off the reel, the strain on the break at the reel being carefully regulated by means of a spring balance, so that the moment the anchor touched the bottom, the reel stopped. The break was then secured at a known strain, such that as the vessel drifted she would take what rope was required. There was thus no paying down of slack line on the top of the anchor. When it was judged that enough rope had been given, the strain on the break was increased, which by gradually bringing the weight of the ship on the anchor, steadied it into the ground. When the anchor was found to be holding, the reel was secured in such a way that, if necessary, it could easily be cast loose, and the vessel being stationary, and at anchor, the work could proceed. It is of great importance that the wire rope should be held fast on board in such a way that it can be easily let go; for, if the anchor begins to drag, then the ship gathers way, and if now the anchor suddenly holds, and it is impossible to veer cable, a very excessive strain is put on the rope in order to stop the ship's way in a very short distance. If, however, the reel can be released, then, by careful working of the break, the anchor can again be steadied into the ground, and the ship stopped without any undue strain being applied to the rope. The rope passes out over the bow of the vessel through a metal block on one of the iron davits used for "catting" the anchor. From this block it is led through another block, which is attached to a spring balance, to the drum of the steam winch. The angle made by the line between the winch and the outer block is always the same; consequently, the strain shown by the spring balance is always the same fraction of the total strain on the line. This fraction, in our particular case, is as nearly as possible one-third. In heaving up the anchor, it is only necessary to watch the spring balance in order not to over strain the line. The moment which requires very careful attention is when the anchor is being started out of stiff ground. By careful handling of the winch, the strain is kept steady until the

anchor comes away, which is shown by the index of the balance jumping suddenly back when the cable is rapidly wound in. It is taken from the winch by the reel, which is wound up by hand. In deep water, the bottom is generally covered by a surface layer of very soft mud, having no holding power; it is necessary, therefore, to allow the anchor to sink by its own weight through this before any great strain is brought on it. During the summer of 1878, the anchor used as described brought up so many valuable specimens of this kind, especially of those existing below the surface layer, that I determined before the next season to provide myself with an anchor which should not only hold the ship, but retain the mud into which it had fixed itself. It is essentially a Trotman's anchor, with an open frame, instead of a solid bar connecting the two palms. To this frame is laced a stout canvas bag, into which any mud sticking to the palm, at the moment of breaking out of ground, falls (Fig. 1). This has proved itself a most successful instrument for exploring the bottom of the seas, especially where the object is to collect the mud itself, rather than the things that live on its surface. Also, as an anchor pure and simple it is most efficient, being constantly used as an ordinary kedge anchor.

The economy in stowage, caused by using wire rope, such as I have described, will be very apparent if we consider the amount of it which can be wound on a reel of moderate size. Let the diameter of the core of the reel be 18 inches, and the diameter of the rope 0.2 inch, then, if carefully and tightly wound on such, a reel will hold sixty turns per foot of length. If the cheeks of the reel be constructed so that rope may be wound on it until the outside diameter of the coil is 28 inches, then the average diameter of one turn of wire rope is 23 inches, and the average circumference one fathom, and the number of turns counted in the direction of a radius would be fifty. We should then have, on a reel 1 foot long by 2 feet 4 inches in diameter, 3,000 fathoms of wire-dredging rope. If the diameter of the cheeks were made, say, 2 feet 8 inches, then 3,000 fathoms would

Fig. 1.



be easily accommodated, even without great care in winding. The whole weight of the line would be 1,000 lbs. It would, however, be advisable, if dredging were to be attempted at such depths, to graduate the size of the line; for it is quite evident that, with 3,000 fathoms of it out, the part at the surface of the water has to sustain all the strain due to the dragging and the weight of the line, or 9 cwt. weight. As the breaking strain when new is 30 cwt. weight, there would be an insufficient margin. Doubts have often been thrown on the trustworthiness of deep soundings, as carried out in the ordinary and simplest way, using a hemp line and heavy sinker, and keeping the ship as stationary as possible. The sources of error most frequently are, or at least were, the compressibility of water and the existence of currents, principally undercurrents.

When a liquid suffers compression, its density is increased; consequently, it was asserted, that at some very great pressure, the density of water will become equal to that of lead, and our sinkers, instead of sinking, will float. Were water compressible in the degree that air is compressible, then the density of water might increase at such a rate as to make lead float, supposing the lead to remain meantime uncompressed; but, whereas the density of air is doubled by raising the pressure worked on it from that of one atmosphere, or 30 inches of mercury, to that of two atmospheres, or 60 inches of mercury, the density of water is only increased by one-twenty thousandth. Now, supposing that the compressibility remains the same at high pressures as at low, it would require a pressure of twenty thousand atmospheres to raise the desity of water from one to two, and more than two hundred thousand atmospheres to raise it to the density of lead. One hundred fathoms of sea water exert a pressure of about eighteen atmospheres; and we may assert with perfect confidence, that the deepest water in the globe is under five thousand fathoms in depth; therefore, even at the greatest possible depths, the density of the water could not be raised by as much as one-twentieth by pressure alone, and the sinking power of lead, which is itself rendered denser by pressure, could not be appreciably affected.

This objection to the validity of deep soundings would not have been worth referring to, were it not that it has been admitted by persons of high authority, and has, by consequence, influenced a large number of persons whose convictions are determined by authority alone. Admiral FitzRoy, for instance, in an appendix to his volume on the voyage of the "Beagle," says: "The depth to which bodies would sink in an ocean several miles deep has not been proved, and there is reason to think that it is much less than people generally imagine," &c. Scoresby, however, twenty years earlier, with his usual acumen, was able to attach its proper value to objections on this ground. He says: "In sounding at great depths, where the pressure of the water becomes equal to, perhaps, several hundreds weight on every square inch of surface, some persons have imagined that even lead cannot sink, but will be suspended midway in the sea. I have conversed, indeed, with very intelligent persons, who could not be persuaded that any dependence could be placed on soundings obtained at a depth exceeding 300 fathoms. Were water a compressible substance, like air, it would be possible that, under a certain pressure, it might become as heavy as lead, so that lead, or any other ponderous body, could only sink to a certain depth; but water being incompressible, or nearly so, it is clear, however great the pressure may be, that it must be the same downward as upward, on any body suspended; consequently, bodies specifically heavier will continue to gravitate downward, whatever be the depth or the weight of the column of water above them."

The other objection to the trustworthiness of deep soundings is a real one, though it is often exaggerated. There is no doubt whatever about the existence of surface currents of great extent and velocity in the midst of the ocean; they are observed and measured every day, as they form a very important factor in the navigator's daily reckoning. Before deep-sea investigation had received the development which it has now, it was quite uncertain whether these currents (the Gulf stream, or the equatorial current, for instance) were confined to the superficial layer of water, or extended in all their force to the bottom. No sooner,

however, had soundings been attempted in them, than it was found that they were comparatively superficial; but, notwithstanding that they were on the surface, and, therefore, immediately under observation, they caused so much deviation in the direction of the sounding line, and such uncertainty in the stationariness of the ship, that soundings so obtained were always considered uncertain. It was then said, if we have these surface currents running from one part of the ocean to another, we must have return currents of some kind, and it is likely that these will be for the most part undercurrents; if, now, a surface current, which you have immediately under your eye, gives you so much trouble, how much more will this be the case with an undercurrent of whose strength, and direction, and depth, you are ignorant?

It must be admitted that when we do meet with currents of the kind imagined, soundings taken in them, whether with wire or hemp line, are very much less to be relied on than those taken in manifestly quiet waters; but, on the other hand, the existence and extent of undercurrents has been very much exaggerated. By far the larger portion of the ocean is, for sounding purposes, practically still water. The surface currents of any importance are easily recognized, and so also are the undercurrents. Just as a physician can, by bringing his experience to bear on the sounds transmitted to him through the stethoscope, divine what is taking place inside the body of his patient, so the experienced seaman can, by observing the behavior of his sounding line, form a fair diagnosis of what is taking place in the depths of the sea. When the sinker passes into a belt of undercurrent, the fact is very soon apparent, and calls for the greatest care in the maneuvering of the ship. Even with the greatest possible care, however, soundings taken under such circumstances, would always be considered to be of doubtful value. If no bottom is brought up, they should be looked on as very doubtful, and even discarded; if bottom is brought up, then we know that the depth is not greater than the line used, and a correction, suggested by observation and experience, may be applied, which will bring the depth very near the truth. Although, as we have said, by far the greater part of the ocean may be looked on as still water, and, therefore, favorable for investigation with the sounding line, it is, nevertheless, of great importance to obtain accurate measurements of the depth of water under well-marked currents.

It is evident that this cannot be satisfactorily done by the sounding line alone, and it early occurred to those who thought on the subject that the method which promised most success was that which should give the depth in terms of the height of the column of water; in other words, the barometrical measurement of altitudes was extended from the land to the sea. Many and various instruments have been suggested and used for the purpose. They are all constructed with a view to record the amount of compression produced on a given mass of a certain elastic substance. From the known law regulating the variation in volume of the substance with variation in the pressure, the maximum pressure to which the instrument has been exposed can be deduced, and from the known density of the water, the height of the column of it, which would produce this pressure, can be calculated, and this height is the depth to which the instrument has been sunk. Many different substances have been used for this purpose, and foremost amongst them air, on account of its great compressibility. For deep work, however, this was quickly found to be a great disadvantage, so great, in fact, that it has never been satisfactorily used at considerable depths.

The compressibility of water was discovered in 1762 by John Canton, and, fifty years later, in extending Canton's original observation to higher pressures, Perkins sank his instruments to various depths in the North Atlantic Ocean, on a voyage from America to this country. These instruments were glass tubes, sealed at one end, filled with water, and inverted in a cup of mercury. In the tube was a steel index which rose with the mercury, and was retained by a spring at the highest point reached. It could be drawn down again, and the instrument so reset by means of a magnet applied to the outside of the tube. Encouraged by the results so obtained, Perkins constructed a hydraulic apparatus, in which he could expose his in-

struments to enormous pressures, which he measured directly by the weight which a plunger could support. He, at the same time, suggested the use of these instruments, or piezometers, for determining great depths. The same suggestion was repeated in 1848 by Aimé, to whom we owe many valuable researches in the Mediterranean, and by the United States Coast Survey a few years after. The same idea occurred to myself in view of my appointment to the "Challenger," and, indeed, it is one of those ideas which necessarily suggest themselves to any one who seriously reflects on the subject. The form of piezometer which seemed to me to be best suited for the purpose was, essentially, that of Perkins, with certain convenient practical modifications. For filling the instruments, I

Fig. 2.

used generally distilled water, and sometimes sea water, or an equivalent salt solution. The bulb and stem of the instrument were so proportioned that, for a depth of one hundred fathoms, the apparent contraction of the water occupied a length of ten millimeters. Some, however, were more, and others less, delicate than these. My object in using water or weak salt solution, as the elastic material, was that, as the temperature of maximum density of these liquids was not far removed from that obtaining in the great mass of deep oceanic water, a considerable inaccuracy in the determination of the temperature of the water would make no sensible difference in the apparent volume of the liquid, and therefore would not sensibly vitiate the depth determination so obtained. Unfortunately, the vicinity of the temperature of maximum density exercises an influence on the compressibility, which counterbalances its advantages from a thermal point of view. A strong salt solution would probably be better. Were the temperature at the bottom of the ocean subject to great variations, the use of distilled water would be quite inadmissible, but over large areas, its variations are confined to fractions of a degree. Hence, the irregularities in the depths given by the piezometer, and due to this cause, are small, though not absolutely to be neglected. I am engaged, at present, in experiments to determine what is the best liquid to use for this purpose.

Another method of measuring the pressure, and through it the depth of the sea, is by means of an instrument much resembling, in principle, the aneroid barometer. Its simplest form is that usually given to a mercurial thermometer. When the pressure on the outside of the instrument is increased, the bulb experiences a tendency to collapse. It yields wherever its walls are weakest, and if the pressure is kept within the necessary bounds, a flattening is produced, which reduces the internal volume of the bulb, and forces the mercury into the stem; if an index is fitted in the steam, its position will indicate that of the extremity of the mercury at the moment of greatest compression. Inventions on this principle have been patented over anp over again in the course of the last twenty or thirty years.

The chief objection to the instrument is that, in practice, it is always filled with mercury. Over the greater part of the ocean the temperature of the water falls as the depth increases. Hence, the mercury will be continually retreating, owing to its contraction due to fall of temperature, while it is being pushed forward by the mechanical collapse of the bulb. Until these two effects compensate each other, there can be no movement of the index, and, therefore, no indication of the depth. In water of tolerably uniform

temperature, as in Polar regions, it ought to do well. Two instruments of this kind were sent to the "Challenger" by Mr. Casella, but they only reached her at the last port before her return to England. They were only used twice, and did not on those occasions give satisfactory results. Sir William Thomson has, within the last year, patented an instrument on the same principle, where the collapsible envelope is a very flat brass tube.

Very analogous to sounding in a current is the operation of sounding from a vessel in motion. We have already described the ordinary operation of heaving the hand lead, by means of which depths up to twelve or fifteen fathoms can be correctly observed under ordinary circumstances. In deeper water, however, and with vessels running at the high speed now common amongst mail steamers, a self-adjusting apparatus is an essential. Up to within the last few years, the commonest form of apparatus of the kind was Massey's sounding machine. In sinking, the friction of the passing water caused a screw fan to rotate, and the number of its rotations was recorded on dials in much the same way as the distance run by a ship is recorded by Massey's patent log. The form of this instrument, requiring, as it does, a system of multiplying wheels, causes it to offer considerable resistance when being hauled on board again; it is, therefore, not suitable, except for vessels going at a moderate speed. Further, if we look to the principle of the instrument, we see that what it in fact registers is the distance traveled by the instrument between the surface and the bottom. If it has been allowed to sink freely, then this distance will be equal to the depth of the water. But if, while sinking, it were exposed to a certain amount of drag, through strain on the sounding line, it would tend to sink sideways, which would put the screw fan to a disadvantage, and vitiate the determination of depth. Practically, this objection has little force, because, in a ship where it is thought proper to execute soundings of the kind, there will be no difficulty in seeing that the sounding line runs out freely.

In arranging for taking soundings from quickly-moving ships, it is important to have not only an instrument which will be dependent only on the true depth of the water for its indications, but also such mechanical appliances as will enable the operation to be carried out safely and expeditiously. To Sir William Thomson is due the credit of having furnished the practical solution of this as of many other problems. His original apparatus for registering the depths was a glass tube, sealed at one end, and coated internally with a chemical preparation (chromate of silver) the color of which was changed by the action of sea water. As the tube, with its included air, sank, the volume of the air diminished, and the sea water penetrated further and further into the tube, until the bottom was reached. On rising to the surface again, the elasticity of the air reasserted itself, and eliminated the water which had entered. The height to which the water had risen was given by the extent to which the internal coating of the tube was altered. The indications of this instrument were always very good, and the practical objection to it lies in the fact that a tube only serves for one sounding, and that, therefore, a number of these have to be carried.

In June, 1879, I patented an instrument, in which the degree of compression to which an enclosed mass of air had been subjected, was measured by the water which had gained admittance to the instrument.

As I now use it, the instrument is represented in Fig. 3. It consists of a glass tube open at both ends, but capable of being closed by a stopper or other means. At some part of the tube a spout is introduced, and the tube is bent over through two right angles immediately above it. When the instrument is to be used, the end is closed, and the line let go; when bottom has been reached, it is brought up again, and we find that a certain amount of water has lodged in the lower part of the tube. It is evident that, as the instrument descends and the air in it is compressed, the water forces its way in through an orifice, and past the spout. This spout is so formed that it delivers the water against the walls of the tube, down which it runs, and collects at the bottom. When the motion of ascent begins, the air, by its elasticity, tends to recover its original volume, and expands in the direction of greatest free-

dom. Now, all the water which has entered has collected below the spout, consequently, in re-expanding, this water will be left undisturbed.

Fig. 3.

Fig. 4.

Assuming that the volume of the mass of air in the instrument varies inversely with the pressure to which it is subjected, we require, in order to be able to construct a scale for our instrument, and so to interpret its results, to know the total volume of the tube, the volume of the part which I call the vestibule, the dimensions and volume of the narrow tube, and of the wide one. Then, if V be the total volume of the tube, and v that of the vestibule, the amount of water which gains admittance when the pressure is raised from one to p atmosphere is:

$$v' = V - \frac{V}{p} v$$

$$= V \frac{p-1}{p} v$$

The methods by which a correct scale of fathoms can be easily applied to any instrument, and engraved either on the glass or on the metal case, or on both, are details of practical instrument making, which need not detain us.

Convenient dimensions for such a sounding instrument are: Total volume, twenty cubic centimeters; volume of vestibule, one cubic centimeter; length, forty to fifty centimeters. In hauling in the sounding line to a vessel under way, the machine comes to the surface a considerable distance astern of the ship, and then has to be towed through the wake, necessarily often dipping under the seas. Each dip which it makes constitutes an independent, though shallow, sounding, and the volume of the vestibule must be so proportioned to the volume of the instrument, that during such immersions no water shall pass the spout. When the instrument has been read, it is at once available for a fresh sounding; it is only necessary to remove the stopper, and let the water run out, and then replace the stopper again. Fig. 4 represents an instrument modified so that it can be used either for great or for small depths, according as either end is closed.*

* After the above was written, my attention was drawn by the Hydrogapher, Captain Evans, to an instrument identical in principle, though differing greatly in the details of construction, invented by Ericsson, and used successfully on board several of her Majesty's ships. It is described and figured in the *Nautical Magazine*, for 1836, and is reported on very favorably by Captain Bisson, of H.M.S. "Partridge," who was accompanied by the inventor, and they obtained successful soundings, in depths up to 80 fathoms, while going at a rate of six knots per hour. Along with the sounding machine, Ericsson brought on board a reel of wire for use, in place of sounding line. Captain Evans informed me that it had been constantly and successfully used under his own eyes, when engaged in the survey of the New Zealand coast, in H.M.S. "Acheron," in 1848, and that it had given great satisfaction.

Sir William Thomson, in his latest specification of patent (February, 1880), recommends a group of three instruments, constructed somewhat on the lines of the above instrument, but composite and of sizes so apportioned that each shall be peculiarly sensitive at certain depths. He also recommends the use of the "elastic bottle gauge," alluded to above, combined with the triple air compression gauge, to give measurements of from 11 fathoms to 300 or 400 fathoms.

It may reasonably be doubted if it could ever be a matter of any importance to the practical mariner to obtain a positive sounding in 300 or 400 fathoms of water, either with or without stopping his ship, and to do so without checking her way would be a very serious undertaking. The weight and wire will not sink at a greater rate than about 100 fathoms per minute, or four minutes for four hundred fathoms, and during four minutes a ship going not more than 10 knots per hour will have advanced by 660 fathoms, so that, when bottom has been struck, there will be at least a thousand fathoms of wire, which, even with steam, could not be reeled in under a quarter of an hour.

The second and more mechanical part of the problem of deep sounding while under way, has been solved by Sir William in an elegant and practical form. His navigational wire sounding reel contains all that is requisite in the smallest possible compass. For my own work, I have made some slight modifications in the details. My reel consists of a solid hard wood core, thoroughly well painted and surrounded with a brass rim, in the hollow of which the wire is wound, and outside of which, on each side, is a break pulley. Pieces of soft hemp line are used for the breaks. The one which is used purely as a friction break is attached at one end to a spring balance, by means of which any definite pressure can be put on the reel. The other is used as a locking break, that is to say, it is taken one complete turn round this pulley in the direction in which it revolves when the wire is running out. When the weight has been observed to strike the bottom, this break is suddenly tightened, which instantly locks the reel when the handles are manned, the breaks thrown off and the wire wound in. I depart also from Sir William Thomson's practice in using galvanized in place of bright steel wire. In order to allow for any possible weakening effect of the galvanizing, I take the wire a size larger. In a small vessel like the "Mallard," I found it very inconvenient working the reel on the taffrail. I have it now well in board, and the wire leads out through a metal block, specially constructed for the purpose, and attached to the flag pole, as high up as a man can reach. In this way the work is carried out without difficulty. The galvanizing is a perfect protection to the wire, and all work with tanks and alkaline solutions is spared. Instead of having a heavy iron link at the end of the wire, I reeve the end of the wire through a piece of ¼-inch block tin gas pipe, about 15 inches long, and then bend it round and splice up the end of the wire so as to form an eye, to which the stray line for sinker and sounding machine can be attached.

In the U. S. Coast Survey Report for 1857, a very ingenious sounding instrument is described by a Mr. Hunt. The instrument consists of an air-tight bag, made of flexible material, with a long flexible tube attached to it. This bag, being filled with air, is sunk to the bottom (in a moderate depth of water) preferably by a heavy grating which surrounds and protects it. The other end of the flexible tube is connected with a Bourdon's pressure gauge in the ship or boat. If, now, this bag be towed over the bottom, and the pressure gauge observed on board, an exact profile of the bottom is given. I am not aware that this instrument has ever been much used for harbor surveying—for which it was intended—and it is not difficult to see where practical difficulties would be likely to occur; it has, however, been used with some success as a tide gauge, and it is clear that, for such a purpose, it possesses many advantages. The bag being securely anchored under water, it can be connected by a pipe of any length with the indicating gauge, or a recording instrument under cover.

For the purpose of observing the temperature of the waters below the surface in lakes and seas, two classes of thermometers have been used, namely, ordinary thermometers and self-registering

ones.* The earliest observations were made with the ordinary thermometer, and it was used in one of two ways; either it was sunk itself to the desired depth, and was so enveloped and protected by badly conducting material, that in bringing it up again, through the layers of water of different temperature, it had not time to alter its own temperature; or a quantity of the water at the desired depth was enclosed in a bucket of suitable construction, and brought to the surface, and then immediately tested with the thermometer. Many very excellent and trustworthy observations exist, which have been made in one of these ways. Our first knowledge of the temperature of the deep water of fresh-water lakes was obtained from the observations of De Saussure, on the lakes of Switzerland, made with a thermometer, so padded and protected that it could be drawn up through 1,000 feet of water, of any temperature likely to be found in nature, without sensibly altering its temperature.

The self-acting bucket, or sea gauge, was used at an earlier date in the determination of the temperature of the deep water of the ocean. The accuracy of the results obtained by this method depends greatly on the skill of the observer. In the case of De Saussure, and of Fisher and Brunner, the results are clearly to be re lied on implicitly. In the experiments with the sea bucket, also, excellent results have been obtained. The results obtained by both methods of experimenting will be the more accurate the more uniform the temperature of the water. The temperature, especially of the bottom water, has also frequently been determined by bringing up a quantity of the mud, and taking its temperature when it arrives on board. This method also gives very satisfactory results when a considerable quantity of mud is at disposal.

Self-Registering Thermometers.—By far the greatest number of observations has been made with self-registering thermometers of one form or another. The first self-registering thermometer was made by Cavendish. He constructed both a maximum and minimum thermometer, and they were of the kind called by the French *a diversment*—out-flow thermometers. In fact, his maximum thermometer is in every particular identical with that known in France as Walferdin's; his minimum is on the same principle, but has a U-formed stem instead of a straight one. The disadvantages of this form of thermometer are two—namely, the indications are not continuous, but by jerks, depending on the size of the mercury drops, and they require to be constantly set, the maximum at a higher, and the minimum at a lower temperature than the one to be observed; they also require constant comparison with a standard. They are, therefore, not suitable for use where many observations have to be made expeditiously.

In the year 1782, Six published a description of the combined maximum and minimum thermometer which bears his name, and which has since continued to assert its place among meteorological instruments as perhaps the best self-registering thermometer. The instrument is too well known to require particular description. It may, however, be noted that Six himself did not use a hair for a spring to keep his indices from falling down, but a fine glass thread soldered to the top of the index, and sticking up in a direction very slightly inclined to that of the length of the index, so that it pressed gently against the sides of the tube. The advantage of the glass over the hair is that it does not lose its elasticity: but, on the other hand, the index takes up more room, and requires a thermometer with a larger stem.

Maximum and minimum thermometers, such as Cavendish's and Six's, when used for deep-sea exploration, show only the maximum and minimum temperatures to which they have been exposed in any one excursion, and a single observation with such a thermometer does not give us with certainty the temperature of the water at the depth to which it has been sunk. Hence, if we had a right to assume that the temperature of a sea or lake might vary in any conceivable way with the depth, these instruments would be valueless. We have, however, no right to make this assumption; we know, on the contrary, that in all seas whose surface is not exposed to a freezing temperature, the temperature of the water will, as a rule, diminish as the

*Proceedings of the Royal Society of Edinburg, 1880.

depth increases, that, therefore, the minimum temperature, as shown by the self-registering thermometer, will, in fact be the temperature at the greatest depth attained by this thermometer. Hence, in such cases, this instrument is to be relied on, and more especially when series of temperatures are taken—that is, when the temperatures at different depths in the same locality are taken, so that the evidence of the decrease of temperature with the increase of depth is rendered as strong as possible. In order to render an account of the state of any lake or sea, as regards temperature, it is absolutely necessary to have such serial observations; hence, for such investigations, the maximum and minimum thermometer is not only trustworthy, but a most valuable and, indeed, indispensable instrument, for it has the great advantage that, as it is in the strictest sense self-registering, any number can be attached to the same line, and so, at one haul, the temperature can be observed at a number of different depths.

For isolated observations, the thermometers just described are not so satisfactory, and very great amount of ingenuity has been displayed in the invention of machines for registering the actual temperature of the water at any depth, independently of that of the water above it.

None of the instruments devised for this purpose have been strictly self-registering; they have all required some assistance from the observer, who, by various forms of mechanical appliance, brings about a catastrophe which leaves its mark on the condition of the instrument. It is obvious that any control which an observer may have over an instrument separated from him by, it may be, three or four miles of cord, is very limited, and is, in fact, confined to his ability to move it towards or from him. By a simple mechanical contrivance, this longitudinal motion may be made to produce one of rotation, and, in fact, the assistance afforded by the observer to the thermometer, to enable it to register its own temperature, consists in his turning it either upside down or through a whole circle when it has reached the desired depth. The first observer who made use of this device was Aimé. His working arrangement is described in "Ann. Chim. Phys.," 1843 [3], vii., p. 497. It is worked by a weight, which is allowed to slip down the line, and which then sets free the apparatus.

His *thermometre a bascule*, along with a number of ingenious modifications of existing forms, is described in the same journal, 1845 [3], xv. p. 5. It was unfortunately only after he was obliged to leave the Mediterranean, which had been the scene of his labors, that he invented the very elegant combination of thermometers by which he was enabled to ascertain the temperature at any depth, no matter what the intervening distribution might be. It is described in the memoir just cited. It consists of two outflow thermometers, so constructed that one of them registers the sum of the rises of temperature, and the other the sum of the falls of temperature, to which it is exposed in any excursion. When they have reached the required depth, they are inverted, and on their way back to the surface they register, as above described, the rises and falls of temperature to which they are exposed. If r be the sum of the rises of temperature, and f the sum of the falls, s the temperature at the depth where they were inverted will be $a=s+r-f$.

If they are allowed to register on the way down, and then inverted at the greatest depth, so as not to register on the way up, the effect will be precisely the same, though the functions of the thermometers will be reversed.

Beautiful and ingenious as Aimé's thermometers are, they have the disadvantages common to all outflow thermometers; they are neither simple enough nor handy enough for work involving many observations. The inverting thermometer, patented by Messrs. Negretti and Zambra, satisfies the conditions required of a thermometer for isolated observations as completely as can be hoped for. It is a mercurial thermometer; the bore of the stem is contracted to the smallest possible diameter at a point about an ich from the neck of the bulb. As long as the thermometer is standing vertically, stem uppermost, the mercury is continuous in stem and bulb; but if it be inverted, the mercury parts at the contraction, the portion in the stem falling down into the point. The stem is graduated from the point

towards the bulb, and the temperature, at the moment of inversion, is read off by the height of the mercury in the end of the stem. This thermometer exists in two varieties, the one with a U-formed stem, which requires to be turned completely round. The turning arrangement for the latter instrument is a somewhat elaborate and expensive instrument, but it answers its purpose. The inverting arrangement, supplied with the half-turn thermometer, is somewhat clumsy and unsatisfactory, The half-turn instrument, when fitted with a suitable investing arrangement, is to be preferred to the others in all work at moderate depths.

Sources of Error in the Indications of various Thermometers.—When an ordinary thermometer, protected by badly-conducting envelopes, is used, it is obviously exposed to alteration of temperature by being pulled through warmer or colder water on its way to the surface. Whether any sensible error is likely to result from this cause, must be determined in each particular case by experience. The more perfectly it resists change of temperature, the longer it will take to assume the temperature of the water. De Saussure left his thermometer down for twelve or fourteen hours for each observation, so that this method is now seldom used. Similarly, also, the method which depends on bringing up a sample of water in a vessel fitted for the purpose, and taking its temperature with an ordinary thermometer, when it reaches the surface, has been discontinued; for although it does not take more time than would be necessary for sending down a thermometer and bringing it up, it is impossible to bring up water from great depths in warm climates without sensible change of temperature.

In the case of outflow thermometers, the delicacy of the instrument is limited by the size of the mercury drops. In the inverting thermometers of Negretti and Zambra an error may arise from the difference of volume of the mercury in the stem, at the temperature at which it was inverted and at that at which it is read. In an extreme case this may amount to as much as O. 4° F.; it can, however, be allowed for.

In Six's instrument there is a possible error from looseness of the indices, in consequence of which they are apt to be shaken out of their places by any jarring of the line. Errors from this source can be avoided to a great extent by attaching the thermometer to the line, by means of an elastic or india-rubber tube

All the self-registering instruments are liable to error from the effects of pressure. The pressure inside a thermometer is never greater than that of the atmosphere when it is sealed up. It may, however, be exposed outside to a pressure of 500 to 600 atmospheres. The effect of this difference of pressure on the outside and inside of the glass envelope is to make it tend to collapse. The bulb of the thermometer is squeezed, and its volume, in consequence, diminished. The liquid which it contains is thereby forced into the stem, and its apparent volume is greater than it would have been, had there been no excess of pressure on the outside of the instrument. The temperature of the instrument is measured by the apparent volume of the liquid which it contains; hence the effect of pressure is to raise the observed temperature above the true temperature. Parrot and Lenz, in 1832, made a series of experiments on the effect of pressure on thermometers. They experimented at pressures up to 100 atmospheres, and observed differences between the apparent and the true temperatures of as much as 20° C. They found that for the same instrument the compression was simply proportional to the pressure. They used a thermometer as a manometer. After this date it was usual to attempt some kind of protection for self-registering thermometers.

Those with straight stems, such as Walferdin's minimum, were sealed up in glass tubes, and so completely protected. Those whose stems were bent, had to be enclosed in metal cases closed with a screw. This form of protection never answered well, as it was impossible to screw on the cover so tight that the water, under the great pressures met with at considerable depth, would not find its way in. In order not to have to abandon the use of thermometers of the convenient form of Six's, the device of protecting the bulb only was hit upon, and it appears that the first thermometer of this kind was used by Captain Pullen, on board H.M.S. "Cyclops." The effect

of pressure on the stem is quite insignificant, and under ordinary circumstances, insensible. For, in nearly all seas where the surface temperature is over 40° Fahr., the temperature of the water diminished as the depth increases, and, therefore, it is the minimum leg which is used, and the effective part of it is that filled with spirit, which may have a length of, at most, three inches. The effect of pressure in diminishing the volume of a short piece of thermometer tubing must certainly be very small, but its actual value can only be determined by removing the bulb, and taking the piece of the stem between the mercury and the neck of the bulb as the bulb of a new thermometer, and determining experimentally the effect of pressure on it. An approximation to the effect may be made by exposing the thermometer to various high pressures, at known temperatures, and observing the rise of the maximum index, then removing the bulb, and calibriating the stem. Knowing, then, the ratio of the volume of this part of the minimum leg, filled with spirit to the whole volume, from the bulb to the maximum index, it may be assumed that the compression will be in the same ratio. And this value will probably be greater than the real one, for the compression of the water produces of itself a certain rise of temperature, and, consequently, rises the maximum index. This can, however, be estimated, either by a comparison with a completely protected thermometer, or by bringing the minimum index also home on the mercury before raising the pressure. If, then, there has been a rise of temperature caused by compression, there will be a corresponding lowering of temperature on relieving the pressure. If the compression apparatus be allowed to stand after the pressure is up, until it has dissipated the heat evolved by the compression, the relief of pressure will cause a corresponding absorption of heat, which will show itself in the position of the minimum index. Some experiments which I have made in this direction show a lowering of temperature of 0.3° Fahr., for the relief of a pressure of 2¼ tons per square inch, the whole rise of the maximum index having been 1.8° Fahr. We may, I think, be quite certain that when the minimum leg is the one used, and the temperature low, the error caused by the effect of pressure on the stem is inappreciable. Cavendish, who invented the self-registering thermometer, foresaw also the most important of the uses to which it could be applied. Thus he suggests that the higher regions of the atmosphere might be investigated by attaching it to a kite—balloons not having been invented. With regard to deep sea explorations, he says:

"If instruments of the nature above described were to be used for finding the temper of the sea at great depths, some alteration would be necessary in the construction of them, principally on account of the great pressure of the water, the ill effect of which can, I believe, be prevented no other way than by leaving the tube open."

This was written in 1757, and it was not till 1762, as already stated, that Canton proved that liquids are compressible. Cavendish, therefore, hoped that as the pressure would not produce distortion of the glass when the tube was open, it would have no visible effect on the apparent volume of the liquid. The device of leaving his thermometer open at the end was adopted by Aimé in some of his experiments, the effect of pressure on the apparent volume of the liquid being determined independently, and a correction applied accordingly. I devised and constructed a mercurial thermometer, or piezometer (Fig. 5) on the same principle, but my object in

Fig. 5.

admitting the water pressure to the inside of the instrument, was to utilize it in shifting the scale of the thermometer as the depths changed. The thing registered in such instruments is always the apparent volume of the liquid, and this varies with the temperature and the pressure. Hence the indications will represent the sum of the effects of the change of temperature and of pressure. If from any independent source we know either of these, we can determine the other. In a sea of uniform temperature throughout its depth, the apparent volume of the liquid would diminish as the pressure increased, and if the temperature increased with the depth, the apparent volume of the liquid would diminish at a slower rate; but it would be always possible to determine the true temperature as long as it did not increase at so great a rate as to dilate the liquid more than it was compressed by the increasing pressure. For the investigation of seas such as the Mediterranean, this form of instrument is most valuable. The method of determining accurately both depth and temperature from the combined reading of a mercury and a water piezometer is explained in the paper communicated to the Chemical Society.*

In the great majority of cases, the most convenient instrument to use is the form of Six's thermometer with protected bulb known as the Miller-Casella thermometer, with the following additions and improvements, which Mr. Casella has applied to them at my suggestion. The size of the instrument is increased so that the degrees are wider apart, a degree Fahrenheit on the minimum leg occupying about three millimeters of its length. Besides the scale of degrees which is attached in enameled slips to the vulcanite at the sides of the stem, there is an arbitrary (millimeter) scale etched on the stem itself. The valves of the division of this scale are ascertained by a careful comparison with a standard thermometer. It is thus possible to read with certainty to a quarter of a millimeter or a twelfth of a degree Fahrenheit. The errors due to the scale not being rigidly attached to the thermometer, and to the difficulty of determining the height of the index by reference to a scale, at the side of, instead of over it, are eliminated. Finally, by having the ordinary scale at the side, the instrument can be used independently of the arbitrary scale, and, even where the arbitrary scale is principally relied on, the scale of degrees enables the observer to know very approximately the true temperature at the moment of observation, without reference to tables, and, by noting on every occasion the reading on both sides, the chance of errors from misreading is greatly reduced. The maximum leg, which is only rarely used, is of larger bore than the minimum one; the degrees, therefore, are closer, and the temperature of the instrument may rise as high as 100° Fahr., without the index entering the terminal bulb. This is a detail of considerable practical importance, for it is impossible always to protect the thermometers, when on deck, from the direct rays of the sun, which would speedily disable the maximum side of the thermometer, if its range were as limited as that of the minimum one.

It will be seen, from what has been said, that there is no one instrument which fulfills all conditions required of a perfect deep-sea thermometer. It is necessary, therefore, for the investigator to use his judgment in the selection of the instrument best suited for the particular case before him. In order to be prepared for possibly occurring cases, he should be provided with thermometers of (*a*) the Miller-Casella type, with improvements just described; (*b*) the mercury piezometer, (*c*) the Negretta and Zambra inverting thermometer. It is well to have several of the first class (*a*), as any number of them can be attached to the line at different depths, and thus much time saved. In my own practice, I generally use four or five at a time. It is not advisable to exceed this number, as the loss in case of accident would be too heavy. Considering the distribution of temperature actually found in lakes and seas of warm and temperate regions, this is the most generally useful instrument, when thorough investigation by means of series of observations is intended. In the particular and frequently occurring case of an enclosed sea, containing a large mass of water, showing no variations of temper-

* *Journal of Chemical Society*, October, 1878. The blocks of Figs. 2, 5, 6 have been kindly lent by the Council of the Chemical Society.

ature when tested by this instrument, it must be replaced by the mercury piezometer (*b*), which possesses the advantage that the position of thermometric scale shifts along the stem according as the depth varies. Also, any number of them can be used at the same time at different depths on the same line. The inverting thermometer of Messrs. Negretti and Zambra (*c*) is the instrument most suitable for isolated observations. It is also of very great use for supplementing and controlling the observations with the other instruments, especially in the case of sea lochs or fjords, where the temperature distribution is often much disturbed by the imperfect mixture of fresh with salt water.

For the successful and expeditious crrrying out of deep-sea temperature observations, the investigator should be furnished with an improved Miller-Casella thermometer for the bulk of the work, and the mercury piezometer and the investing thermometers for particular cases. All the thermometers, of whatever type, should be carefully compared with a good standard, and the result stated in terms of its scale.

For the determination of the specific gravity of the water, it is necessary to have an instrument of considerable delicacy, which can be used in all moderate weather at sea. The specific gravity of a liquid is ordinarily determined in one of two ways, either with the specific gravity bottle, when the weight of a known volume of the liquid is directly observed, or with the hydrometer, when the volume of a known weight is observed. A special modification of the hydrometer, namely specific gravity bulbs, has long been in use for special purposes, and they have been used by Dr. Carpenter and others for sea work. The only objection to their employment, in work of purely scientific interest, is that each bulb, being in effect a separate hydrometer, has to be separately tested for its weight and volume, and for change of apparent density with changes of temperature. With the large number of bulbs which is necessary, this involves an enormous amount of labor expended, without corresponding advantage. Sets of hydrometers, graduated so as to include all specific gravities naturally occurring in the sea, have been used. When each hydrometer has been constructed of the requisite delicacy, and of workable proportions, it is necessary to have a set of ten hydrometers; and the same objection obtains as in the case of the bulbs. For the work of the "Challenger," an instrument of suitable size and proportions was constructed. Its stem carried an arbitrary scale (millimeters), and was carefully calibrated: the weight of the whole instrument was also carefully determined, and also the dilatability of the body. The instrument was entirely of glass. By a contrivance similar to that used in Nicholson's hydrometer, weights could be placed on the upper sub-cavity of the stem. By this means the range of usefulness of one hydrometer can be extended far beyond the limits occurring naturally in the sea.

In prosecuting independently this work, I have improved on some of the details of the instrument, without, however, in any way altering its general character. In the "Challenger" instrument, the body was a cylinder, containing about four diameters in its length; in the heavier form it is a sphere of about the same volume, this materially reducing the length of the instrument. Instead of a small brass table, and weights to be laid on it, the weights are hollow brass cylinders, closed at one end, and widened to flange at the open end with others in the form of flat rings, which can be slipped over the cylindrical weights, and then rest on the flange. These are small mechanical details, which, however, greatly affect the handiness of the instrument, and they are therefore of importance. The following is a description of the instrument used for the whole of the work done during the cruise of the "Challenger." The stem, which carries a millimeter scale 10 centimeters long, has an outside diameter of about 3 millimeters, the external volume of the divided portion being 0.8607 cubic centimeter; the mean volume of the body is 160.15 cubic centimeters, and the weight of the glass instrument is 160.0405 grammes. With this volume and weight, it floats in distilled water of 16° C. at about the lowest division (100) of the scale. In order to make it servicable for heavier waters, a small brass table is made to rest on the

top of the stem, of such a weight that it depresses the instrument in distilled water of 16° C. to about the topmost division (0) of the scale. By means of a series of six weights, multiplies by 1, 2, 3, 4, 5, and 6, of the weight of the table, specific gravities between 1.00000 and 1.03400 can be observed. It is not necessary that these weights should be accurate multiples of the weight of the table; it is sufficient if they approach it within a centigramme, and their actual weight be known with accuracy. The weights of the table and weights in actual use are:

Weight of table.....		0.8360	grammes.
Weight of weight No.	I.	0.8560	"
" "	II.	1.6010	"
" "	III.	2.4225	"
" "	IV.	3.1245	"
" "	V.	4.0710	"
" "	VI.	4.8245	"

For oceanic waters, the hydrometer is always used with the table, and either No. IV. or No. V. weight.

When the mechanical part of the construction of the instrument was finished, with the exception of the closing of the top of the stem (which, instead, was widened into a funnel shape, large enough to receive the ordinary decigramme weights), the calibration of the stem was effected by loading the stem with successive weights, and observing the consequent depressions in distilled water of known temperature. This done, the top was sealed up, and the instrument carefully weighed. The expansion of the body with temperature was determined in a similar manner, by reading the instrument in distilled water of various temperatures. The coefficient of expansion of the glass was then found to be 0.000029 per degree Centigrade.

For using this instrument at sea, about 900 cubic centimeters of sea water are taken, and the containing cylinder placed on a swinging table, in a position as near the center of the ship as possible. The observation with the hydrometer, loaded with the necessary table and weight, is then effected in the ordinary way, the accuracy of the readings being but little affected by rolling; pitching, however, is found to have a distinctly disturbing effect; and when it is in any way violent, it is advisable to store the specimen of water till the weather improves.

The temperature of the water at the time of observation is determined by one of Geissler's "Normal" or standard thermometers, graduated into tenths of a degree Centigrade; and it is essential for the accuracy of the results that the water, during the observations of the hydrometer, should be sensibly at the same temperature as the atmosphere, otherwise the changing temperature of the water makes the readings of both the hydrometer and the thermometer uncertain. At low temperature (below 10° or 12° C.) a tenth of a degree makes no sensible difference in the resulting specific gravity; but, at the high temperatures always found at the surface of tropical seas, rising sometimes to 30° C., the same difference of temperature may make a difference of three to four in the resulting specific gravity.

Having obtained the specific gravity of the water in question, at a temperature which depends upon that of the air at the time, it is necessary, in order that the results may be comparable to reduce them to their values at one common temperature. For this purpose a knowledge of the expansion of sea water with temperature is necessary.

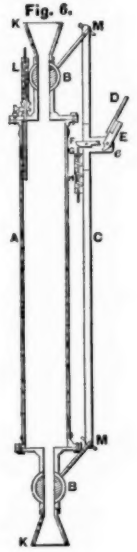
This had been determined with sufficient accuracy for low temperatures by Despretz and others; but as the temperatures at which specific gravity observations are usually made are comparatively high, their results were of but little use, directed as they were chiefly to the determination of the freezing and maximum density points. When the late Captain Maury was developing his theory of oceanic circulation, owing to difference of density of the water in its different parts, he found the want of information on this important subject. At his request the late Professor Hubbard, of the National Observatory, United States, instituted a series of experiments, from which he was enabled to lay down a curve of the volumes of sea water at all temperatures, from considerably below the freezing point to much above what obtains even in the hottest seas. The results are published in Maury's "Sailing Directions," 1858, vol. i., p. 237, and have evidently been carried out with great care. The composition of different oceanic waters varies, even in extreme cases, within such close limits that the

law of thermal expansions is sensibly the same for all of them; of this, Hubbard's experiments afford satisfactory proof. In the table which gives the results of all his experiments, he takes the volume of water at 60° Fahr. as his unit. In order to avoid much useless calculation, I have been in the habit of reducing my results to the same temperature (15.56° C.), while, for a like reason, I have retained the specific gravity of distilled water at 4° C. as the unit. The choice of a common temperature, to which the results should be reduced, and of a unit of specific gravities, is a purely conventional matter; and in choosing the above-mentioned ones, in the first instance, I was moved solely by a desire to save calculation. For every water, however, there is one temperature to which it would be natural to reduce its specific gravity, namely, the temperature which the water had when in its place in the ocean; and in this sense all my results during the cruise have been reduced. Hubbard's table of the change of volume of a mass of sea water, with change of temperature, enables us very easily to reduce any observed specific gravity from the temperature of observation to any other temperature, say 15.56° C.

Collection of Samples of Water.— The water from the bottom was usually collected in the so-called "slip" water bottle, which has been described by Professor Jacobsen. Water from intermediate depths is obtained in an instrument represented in section in Fig. 6. It is made entirely of brass, which, however, might advantageously be nickel-plated. It consists of a cylinder A, terminated at both ends by similar stop cocks B B, which are connected by the rod C. This rod carries, near its upper extremity, a piece of stout sheet brass D, 10 centimeters long by 15 broad, soldered to the casting E, which is movable about the axis *e*. The function of this part of the apparatus will be more easily explained by describing the manipulations necessary when collecting water.

When intermediate water is to be obtained, the water bottle is firmly attached to the sounding line, which carries at its end usually a lead of 56 lbs. or 1 cwt.; the stop cocks are then opened, giving them, with the rod C, the position represented in the figure. The line is then lowered carefully by hand, until the water bottle is close to the surface, when it is let go, and the line allowed to run out without a check. During its passage downwards the water courses freely through it, being considerably assisted by the conical end pieces K, K. When the requisite depth has been reached, the line is

Fig. 6.



checked again at the same mark, and finally hauled in altogether by the donkey engine. When the line is hauled in at first the flap D falls down into a horizontal position, when it is caught by the movable piece of brass F, which moves around an axis *f*, and is supported on the side opposite to E by the rod G, which rests on the spiral spring H. The water rushing past D, when thus in a horizontal position, exercises a sufficient pressure upon the rod to close the stop cocks B, B. When the speed with which the bottle is hauled through the water is increased, the pressure on D becomes so great, that it overcomes the tension of the spring H, and E passes the catch F, when the rest of the journey upwards is performed with the flap, D, hanging down, and therefore offering the least possible resistance to the water. The object of at first hauling in only a couple

of fathoms or so, and letting the line go again, is to insure the cocks being closed. For, supposing after the first hauling in they were not quite closed, by letting the instrument descend through the water the flap D gets itself again, and, on heaving in, it shuts down the stop cocks, which were before but partially closed; or, if they were closed before, it only shuts them the tighter. When the water bottle has been brought it is only necessary to substitute for the lowermost brass funnel a small nozzle, when the water may be tapped into any vessel destined to receive it. This done, the bottle may be at once lowered to any other required depth, much time being spared by not having to detach it each time. At the upper end of the bottle a small spring safety valve, I, is introduced, in order that the considerably denser water from below may be able to make room for itself as the surface is approached. In order that the instrument may properly do its work, it is evident that, first, the stop cocks should be so stiff that the weight attached to their levers be not sufficient to close them; and, secondly, the spring H should be so strong as to ensure the shutting of the cocks before it itself gives way. These conditions are secured by the following means of adjustment. The stop cocks can be made stiff in the usual way, by lightening the screws which screw the "keys" in the bands; the tension of the spring H can be increased or diminished by means of a screw at the lower end of the tube containing it; and the mobility of the stop cock can be regulated by means of the screws M, M. Although from this description the operations of adjustment may appear complicated, it is, in fact, practically very simple. After the first time of use it is rare that any further adjustment is required than a turn of the screws M, M. The diameter of the apertures at either end is necessarily smaller than that of the cylinder; it is, therefore, impossible for the water in it to be entirely changed while descending through a distance equal to its own length. It became a question, therefore, for experiment to decide what actually was the rate of change of water. To this end a few experiments were made in a fresh water lake. The bottle being filled with water containing some yellow prussiate of potash was sunk in the lake, until the surface of the water was on a level with the upper stop cock when the stop cocks were opened, and the lime let go. On being brought up again the contents were treated with the solution of perchloride of iron. It was found that, when the bottle had been sunk to a depth of a fathom and a-half, the water had been entirely changed, the iron solution being wholly without action on it. We may be certain then that the water which we obtain by this means is an average of the last two fathoms through which the bottle has passed.

The weight used as a sinker should be chosen so as to impart sufficient velocity not to lose time unnecessarily over the operation, and, at the same time, not to give an excessive velocity at the depth where the water is to be collected, because the rate of change of water depends on the friction of the water inside the bottle, and so on the velocity of descent. In practice, for depths over 100 fathoms, a weight of 112 lbs. was used, and for depths from 25 up to 100 fathoms, a weight of 56 lbs. was used. For less depths the weight of the bottle itself was sufficient. The velocity of descent at the depth where the water is to be collected should not exceed 12 feet per second. The mean velocity for the interval between 75 and 100 fathoms from the surface was, with 66 lbs., nine feet, and with 112 lbs. eleven and a-half feet per second.

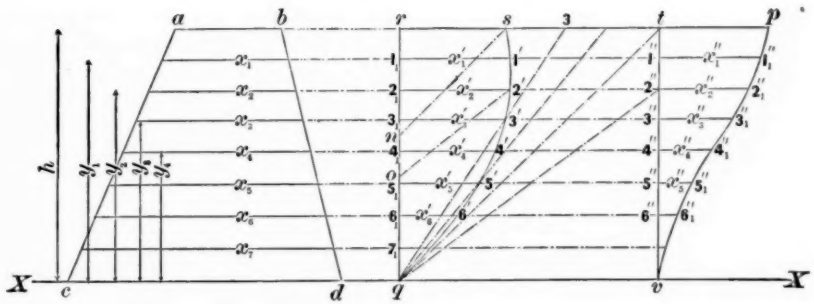
When once let go, it is essential that the line should run out to the required depth without a check; it is then, however, immaterial, as far as the water bottle is concerned, what interruptions occur in heaving in. The fulfillment of the condition of running out without a check never presented any difficulty on board the "Challenger," depending as it does on the care of those who take the line. When, however, by accident a check does occur, the line is stopped, and the water bottle brought up again, reset, and sent down again. In order to utilize any such accidents, it is usual to take the water from the greatest depth first; then, if a check does occur, it may occur at one of the desired intermediate depths, and so no time would be lost. In designing the water bottle, it had been my intention to use it not only for collect-

ing water, but also as a flask, so that the atmospheric gases could be boiled out of it without transvasing the water. In practice, however, I have not been able to get air-tight stop cocks, besides which, it would make an inconveniently large apparatus in a very small laboratory. I have spoken of this water bottle as being only used for intermediate waters, but there is no reason why it should not be used for bottom water; indeed, where the sounding lead does not weigh over 1 cwt., it is frequently used for this purpose. In the case of deep soundings however, where a weight of three, and sometimes four hundred weight is used, the "slip" water bottle is always preferred.

MOMENT OF INERTIA OF PLANE FIGURES OF ANY FORM.

By LIEUT. G. S. CLARKE, R.E.

From Papers of the Royal Engineer Institute.



THE moments of inertia of figures of simple geometrical form are most readily found by integration. Those of irregular figures, such as a rail section, can be determined by graphic methods alone.

The following simple general method is believed to be entirely new.

Suppose that the moment of inertia of the trapezium *abcd* about any axis XX is required. Draw any ordinates $x_1, x_2, \ldots$ of the trapezium and produce them as shown. Draw any line *rq* perpendicular to XX. Let $y_1, y_2 \ldots$ be the respective perpendicular distances of $x_1, x_2 \ldots$ from XX, and let *h* be the perpendicular height of the trapezium. From *r* set off *r*3 equal to any ordinate x_3; join 3*q* cutting x_3 produced in 3′. Repeat the process for all the other ordinates x_2, x_4, x_5, . . . (obtaining the points 1′, 2′, 4′ . . .) finally make *rs*=*ab*.

Let $x_1', x_2', \ldots$ be the ordinates of 1′, 2′, . . . measured from *rq*; *i.e.*, $x_1'=1_1 1'$; $x_2'=2_1 2'$, etc.

Then:

$$\left.\begin{aligned} \frac{x_1'}{y_1}&=\frac{x_1}{h};\ \text{or, } x_1=h\frac{x_1'}{y_1}\\ \frac{x_2'}{y_2}&=\frac{x_2}{h};\ \text{or, } x_2=h\frac{x_2'}{y_2}\end{aligned}\right\} \quad \ldots\ldots \quad (a).$$

and so on.

Now the moment of inertia (I) of the trapezium about XX is $\Sigma(x_1' y_1^2)=h\Sigma(x_1' y_1)$ but $\Sigma(x_1 y_1)=\mathrm{Y}.\Sigma(x_1')$

Where Y is the distance of the center of gravity of the figure *rsq* from XX. Hence calling A the area of the figure *rsq*

$$\mathrm{I}=h.\mathrm{Y}.\mathrm{A}.$$

To determine I, therefore, it is necessary to know the area of *rsq*, and also the position of its center of gravity.

So far the construction is of course perfectly well known.

Now, make *rt*=*h* and draw *tv* perpendicular to XX, and cutting the produced ordinates in 1″, 2″ . . .; join any of these points; *e.g.*, 2″ to *q* and draw 2′0 par-

allel to $2''q$. Call the distance $2_1 0$, x_2'' and set off x_2'' horizontally from $2''$, thus obtaining the point $2_1''$. Repeat the construction in the case of x_1', x_2', . . . thus obtaining the ordinates x_1'', x_2'', . . . and the points $1_1''$, $3_1''$, . . . ; finally draw sn parallel to tq and make $tp=rn$.

Then:

$$\frac{x_1''}{1_1 q}=\frac{x_1'}{1_1 1''}, \text{ or, } x_1''=\frac{x_1' \cdot y_1}{h}$$

Similary $x_2''=\frac{x_2' y_2}{h}$ and so on, but from (a)

$$x_1'=\frac{x_1 y_1}{h};\ x'_2=\frac{x_2 y_2}{h};\ \text{etc.}$$

Hence $$x_1''=\frac{1}{h^2} x_1 y_1^2$$

$$\Sigma(x_1'')=\frac{1}{h^2}\Sigma(x_1 y_1^2)$$

But $\Sigma(x_1'')$=the area of the figure tpv=A′ and $\Sigma(x_1 y_1^2)$=I. Hence

$$I=A'.h^2.$$

Since h is known it is merely necessary to obtain the area of the figure tpv. This can be done by cutting it up into approximate trapeziums, or very conviently by a planimeter.

The curve sg, which need not, of course, be drawn, is evidently a parabola.

The method is perfectly general and can be applied with equal facility to figures of all forms with any positions of the axis XX, and its great simplicity will be appreciated by any one who tries it.

The construction requires very little more time than the ordinary one, and when completed, it remains merely to find the area of a figure instead of an area and a center of gravity.

THE GASKILL COMPOUND PUMPING ENGINE.

By JOHN W. HILL, M. E.

The Gaskill pumping engine is a new design of compound engine for city water supply, built by the Holly Manufacturing Company, of Lockport, N. Y., the first specimen of which was furnished the City of Evansville, Indiana.

By the courtesy of the trustees I am permitted to publish the following preliminary report upon the performance of the engines:

Committee on Water Works:

Gentlemen—Acting under your instructions, in behalf of the City of Evansville, I have made test trials of the engines recently erected in your pumping house by the Holly Manufacturing Company, of Lockport, N. Y., for your city water supply, and have to report to you thereon as follows:

The engines, two in number, are of the compound condensing type, with cylinders set parallel, and centers separated eight feet. The high pressure cylinder has a diameter of twenty-four (24) inches, and the low pressure cylinder a diameter of forty-one (41) inches. Each piston has a stroke approximately thirty-six (36) inches. The pistons of each engine are connected to cranks set at quarters on the fly wheel shaft mounted in bearings on the gallows frame overhead.

The contract between the City of Evansville and the Holly Manufacturing Company provides for "two sets of duplex pumping engines, each of four millions (4,000,000) gallons capacity each twenty-four (24) hours at a piston speed of one hundred and eight (108) feet per minute."

With engines pumping direct into the distributing mains, it is impossible to measure the water delivered through the force pipe by any of the usual methods, and as the supply is drawn from the river (Ohio) through long lines of suction pipe connected to the suction of the pumps, and subject to wide differences of head, it becomes practically impossible to measure the water on the suction side of the pumps. I have therefore adopted the only convenient method for determining the capacity of the engines, that of calculating the discharge and deducting therefrom a minimum slip.

The data for this purpose were taken by myself in the presence of your superintendent (Roberts) and a representative of the Holly Manufacturing Company, and are as follows:

Engine No. 1:

H.P.	cylinder	pump	piston,	diam.,	17.98	ins.
"	"	"	" rod,	"	3.376	"
L.P.	"	"	"	"	18.00	"
"	"	"	" rod,	"	3.422	"
H.P.	"	"	" stroke,	"	35.965	"
L.P.	"	"	"	"	35.985	"

From which I estimate the capacity of engine No. 1 as

$$\frac{2(17.98^2\times.7854)-(3.376^2\times.7854)\times35.965}{231}$$

$$=77.653$$

gallons, calculated capacity of the pump worked by the piston of H. P. cylinder per revolution, and

$$\frac{2(18^2\times.7854)-(3.422^2\times.7854)\times35.985}{231}$$

$$=77.850$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.503 gallons.

The mean stroke in feet of both pumps is

$$\frac{35.965+35.985}{2\times12}=2.9978$$

corresponding to

$$\frac{108\times60\times24}{2.9978}=25938.01$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge, $155.503\times25938.01\times.96=3,872,101$ gallons.

Engine No. 2:

H.P.	cylinder	pump	piston,	diam.,	17.99	ins.
"	"	"	" rod,	"	3.376	"
L.P.	"	"	"	"	18.00	"
"	"	"	" rod,	"	3.422	"
H.P.	"	"	" stroke	"	36.023	"
L.P.	"	"	"	"	35.967	"

From which I estimate the capacity of engine No. 2 as

$$\frac{2(17.99^2\times.7854)-(3.376^2\times.7854)\times36.023}{231}$$

$$=77.882$$

gallons, calculated capacity of the pump worked by the piston of the H. P. cylinder, per revolution, and

$$\frac{2(18^2\times.7854)-(3.422^2\times.7854)\times35.967}{231}$$

$$=77.811$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.693 gallons.

The mean stroke in feet of both pumps is

$$\frac{36.023+35.967}{2\times12}=2.9995$$

corresponding to

$$\frac{108\times60\times24}{2.9995}=25932.6$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge,

$155.693\times25932.6\times.96=3,874,628$ gallons.

The contract provides that the duty shall be eighty millions (80,000,000) foot pounds, per one hundred (100) pounds of coal burned under the boilers, with an evaporation from the temperature of feed of nine pounds of steam per pound of coal; and that the duty shall be estimated from the calculated discharge of pumps per revolution, the revolutions of engine during the trial, and the total head pumped against as the numerator of a fraction; the denominator of which shall be the net water delivered as steam to the engine divided by nine hundred (900). "The weight of water pumped to be taken at 8.34 pounds per gallon."

"Each engine to be operated continuously for twenty-four (24) hours for duty trial."

The duty trial of engine No. 1 commenced at 11.15 A. M., January 27th, and terminated at 11.15 A. M., January 28th.

The counter reading at beginning of trial, was.....	1392
And, at end of trial, was.....	27762
Difference—revolutions.....	26370

The head pumped against in feet, was:

By gauge on force pipe.....	135.6931
By difference between center of gauge on force pipe and mean level of water in river during trial.....	29.055
By friction head suction pipe...	2.3806
By friction head force pipe.....	.161
By friction head 20″ elbow in force pipe.....	.0155
By allowance for resistance of water passages in pumps....	2.3
Total head.....	169.6052

The calculated discharge of pumps per revolution of engine has been stated as 155,503 gallons.

The water weighed to the boilers during the whole trial was 65228 pounds, from which is deducted the following quantities:

Drawn off to calorimeter.....	172.125
Leakage between weighing tank and boilers.....	50.322
Entrained in the steam, 1.93 per cent.....	1254.607
Total deduction.....	1477.054

and net steam delivered to the engine becomes 63750.946 pounds, corresponding to an expenditure of 7083.44 pounds of coal, upon the evaporation stipulated in the contract.

From which I estimate the duty of engine No. 1 as

$$\frac{155.503 \times 26370 \times 8.34 \times 169.6052}{70.8344}$$

$$= 81,885,917.12.$$

The duty trial of engine No. 2 commenced at 10.45 A. M., January 29th, and terminated at 10.45 A. M., January 30th.

The counter reading at beginning of trial was.....	501
And at end of trial.....	27986
Difference—revolutions.....	27485

The head pumped against in feet was

By gauge on force pipe.....	141.372
By difference between center of gauge on force pipe and mean level of water in river during trial.....	32.437
By friction head suction pipe....	2.5925
By friction head force pipe.....	.1737
By friction head 20″ elbow in force pipe.....	.0169
By allowance for resistance of water passages in pumps	2.3
Total head.....	178.8921

The calculated discharge of pumps per revolution of engine has been stated as 155,693 gallons.

The water weighed to the boilers during the whole trial was 68238 pounds, from which is deducted the following quantities:

Drawn off to calorimeter.....	168.875
Leakage between weighing tank and boilers.....	50.322
Entrained in the steam, 4.7489 per cent.....	3230.145
Total deduction.....	3449.342

and net steam delivered to the engine becomes 64788.658 pounds corresponding to an expenditure of coal under the terms of the contract, of 7198.74 pounds.

From which I estimate the duty of engine No. 2 as

$$\frac{155.693 \times 27485 \times 8.34 \times 178.8921}{71.9874}$$

$$= 88,688,866.4.$$

In regard to the capacity guaranteed for the engines, I am inclined to believe, in view of the stipulated dimensions of pumps and piston speed, that the incorporation in the contract of four millions (4,000,000) gallons capacity was unintentional, as the prescribed data of the contract prohibits this discharge.

You will observe that both engines have exceeded the contract duty, one by *nearly two millions*, and the other by more than *eight and one-half millions*.

In the general report, which I shall submit at an early date, will be given all the data taken during the trials, together with an inquiry into the precise performance of the engine, as developed from the indicator diagrams.

A PULVERULENT lubricating material for axles, shafts, &c., is prepared by Herr Drechsler, of Dresden, thus: The finest graphite powder is worked up thoroughly with egg-white, or yellow, or both, to a firm dough, which, in a metallic vessel, is kept in a vessel of boiling water, till the egg-white and yellow are fully coagulated. The mass is then dried at 90° C., so thoroughly, that it can be bruised or stamped to powder. This powder is applied to a slowly-revolving axle or shaft, till axle and bush take the peculiar dark shine of graphite.

STREET CLEANSING IN PARIS.

By M. VAISSIERE.

From Foreign Abstracts of Institution of Civil Engineers.

The cleansing of the public thoroughfares in Paris, formerly undertaken by the Prefect of Police, is now a function of the Prefect of the Seine. The staff consists of two chief engineers, one for each group of arrondissements, one group being subdivided into three sections, each under the charge of an executive engineer; and the other into five sections, similarly supervised. These sectional engineers have under them fifty-one superintendents and sixty-one overseers, whose employment imposes upon the municipal budget an annual cost of 260,000 francs. The scavenging plant is kept in a central depot, where materials of every description are stored and classified, for ordinary and extraordinary service, when snow and ice render additional assistants necessary.

The depots contain supplies of chloride of lime, sulphate of zinc, sulphate of iron, and carbolic acid, as disinfectants; and hydrochloric acid, nitro-benzide (acide de mirbane), as cleansing agents. The chloride of lime, of a strength of 100° to 105°, is successfully employed for the disinfecting of places tainted with urine or fæcal matter, also for the cleansing of gutters carrying sewage water. Sulphate of iron and sulphate of zinc are both used under the same conditions. Sulphate of iron possesses the disadvantage of rusting objects to which it is applied. Sulphate of zinc is stronger in its action, but costs a little more. It produces no smell, nor does it leave any trace. It is much employed in summer for washing and watering the basements of the Halles Centrales, used for fish, poultry and offal. At a strength of $\frac{1}{4}$, and mixed with 3 per cent. of sulphate of copper, sulphate of zinc makes a good disinfecting liquor, which preserves its qualities a long time and is of great use in private houses. Carbolic acid is not, strictly speaking, a disinfectant; it does not act like chloride on putrid matter, but arrests and prevents fermentation, doubtless by destroying the spores. It is, therefore, always employed when it is desired to destroy the germs of putrid fermentation. It is used at a strength of about $\frac{1}{40}$, say a gallon of the acid to 40 gallons of water. At strengths of $\frac{1}{100}$ and $\frac{1}{200}$ it gives good results for watering once or twice a week in summer those parts of the Halles Centrales liable to infection. It is even used as low as $\frac{1}{1000}$ for watering streets and gutters. Hydrochloric acid is applied to urinals and slaughterhouses. In places much encrusted with tartar it is used at a strength of $\frac{1}{5}$. Lowered to $\frac{1}{10}$ it cleans smooth walls and flags efficiently. In ordinary rinsings a strength of $\frac{1}{15}$ suffices. It leaves a disagreeable odor behind, which is, however, quickly dissipated. Mirbanic acid (nitro-benzide) is more energetic than the foregoing, but it produces a disagreeable smell of bitter almonds, and leaves a white film which has to be washed off. It is used at the same strengths as hydrochloric acid. The annual cost for plant and disinfecting materials of all descriptions is £8,800 (220,000 francs).

The engineers of the city of Paris are also charged with the sweeping of the roads, an area of 12,916,800 square yards being cleaned between 3 and 6 A. M. in summer and between 4 and 7 in winter. The carts for removing the public and private refuse work from 6 to 8 A. M. in summer and from 7 to 9 in the winter. The filling of each cart is attended to by the driver aided by two shovelers, the latter having to provide during the rest of the day supplemental sweepings wherever required, to rinse the gutters twice a day, and to clear and disinfect urinals, &c. These matters are ordinarily finished by 4 o'clock in the afternoon, except in unfavorable weather. The engineers have all at their disposal a staff of:

	fr. c.	fr. c.
2,200 men at from	2 50 to	4 0 per day.
950 women "	0 20 to	0 25 per hour.
30 children (boys) at		0 20 per hour.

In addition there are one hundred and

ninety mechanical sweepers, and as each machine represents the effective work of ten men, the total scavenging staff may be considered as composed of nearly five thousand laborers.

The mechanical sweepers which, after numerous trials and much hesitation, have been introduced into Paris, are the English machine, improved by M. Sohy, and the machine of M. Blot, the former being preferred. The mechanism of both is simple, works with regularity, and occupies little space; it consists of a framework upon two wheels, with a seat for the driver. At the back is placed the sweeping apparatus, composed of an inclined circular bass broom, actuated by gearing driven from one of the wheels of the carriage. By means of a clutch the driver can from his seat easily put the broom in or out of gear. The machine is employed in all weathers, and works as well on paved roads as upon macadam or asphalt. Each machine weighs rather over 14 cwt., and can be drawn by one horse. It sweeps about 6,578 square yards per hour. The cost of the machine is £40, and its annual maintenance, exclusive of renewals of the brush, £8. The cost of a new brush is about £2 16*s.* (70 francs), which will work for from one hundred and sixty to one hundred and eighty hours.

The Paris mud no longer possesses the manurial strength of former times, and in consequence the receipts derived by the municipality from this source have greatly diminished. It is at present disposed of by public tender to responsible contractors for terms of about four years. For its removal there are daily employed five hundred and twenty carts, and nine hundred and eighty horses. The average bulk removed per day is about 2,223 cubic yards (1,700 cubic meters).

When a fall of snow occurs, attention is first directed to clearing the footpaths and crossings, so as to insure uninterrupted circulation of foot passengers. The town scavengers sand the roads wherever it is necessary for the carriage traffic. At the same time numerous auxiliaries are organized to remove the snow from the principal thoroughfares, in the order of their relative importance. For removing the snow the General Omnibus Company are bound by their concession to furnish fifty wagons, and carts are specially arranged for with the providers of sand and gravel at the beginning of winter, the contractors for maintaining the public roads being also bound to hold their carts at the disposition of the sectional engineers. In certain cases the half-melted snow is swept into the sewers, especially those carrying warm water. Melting by steam has been tried, when a continuous jet was introduced into a mass of banked snow, but it melted very slowly at first, and the melting ceased after the cavity had increased to a certain size. Two descriptions of snow plough are kept in store, one for manual, the other for horse power; but they have never been used, as the coating of snow seldom attains sufficient thickness, and as it is too quickly compressed and hardened by the traffic. As a rule the sum allowed in the budget, about £7,000, suffices for the extra labor incurred; but occasionally severe winters cause this to be greatly exceeded, as in 1875–76, when the increase amounted to £8,000.

Both hose and carts are used for watering the thoroughfares, the former for the boulevards, the avenues, and a certain number of first-class streets. The watering plant belongs to the municipality. Three descriptions of carts are in use, two heavy wooden ones are now being superseded by the third, Sohy's cart, made of sheet iron. The carts contain 220, 242 and 286 gallons respectively, and will water from 2,400 to 3,350 square yards. The watering by hose is attended to by the ordinary street cleaners, who can easily water 24,000 square yards in thirty-five minutes, deducting the time necessary to connect the apparatus with the mains. There are three hundred and twenty-two water carts, which on the average disperse 1,311,200 gallons of water over a surface of 7,139,-163 square yards. A surface of 2,783-,092 square yards is watered by hose, and this system is being greatly developed on account of its convenience and cheapness. The annual cost of watering is £18,000.—*Annales des Ponts et Chaussées.*

REPORTS OF ENGINEERING SOCIETIES.

THE AMERICAN SOCIETY OF CIVIL ENGINEERS.—The January and February issues of Transactions, contain :

Paper No. 214. "The Strongest of the Bronzes; a Newly Discovered Alloy of Maximum Strength," by R. H. Thurston.

No. 215. "Renewal of Foundation and Transfer of a Lighthouse in Pascagoula Harbor," by J. W. Putnam.

No. 216. "The Sewerage of Memphis," by F. S. Odell.

The papers are fully illustrated and the discussions of the latter paper are of unusual interest.

POLYTECHNIC ASSOCIATION OF THE AMERICAN INSTITUTE.—At the meeting of the 17th March, the paper for the evening was by Prof. Plympton upon the aneroid barometer. This instrument has been greatly misunderstood, and has been much abused because people, in buying it, have often supposed that they would be able, by inspection, to read off the elevations at which they made their observations, in the same way that they would note the temperature upon a thermometer. Like the mercurial instrument, it is a measure of the pressure of the atmosphere at any given time.

In torrid zones, where the variations of pressure are sudden, especially those just preceding severe storms of wind, &c., the mercurial instrument does not indicate with sufficient rapidity. It is an accurate balance, though rather slow to swing. Its numerous disadvantages as a portable instrument were mentioned, and its construction illustrated experimentally. The construction of the aneroid was then described, and drawings were made upon the board. Almost a dozen different styles and sizes of instruments were then exhibited, from the 5-inch instrument to the delicate affair no larger than a watch.

The paper of March 24th was upon glass and cements, by Dr. John Phin, of the *American Journal of Microscopy*.

Cements are to be divided into four classes, according as they dry, congeal by oxydation, harden by cooling, or "set" by other chemical changes. First are those which harden by evaporation. Under this head may be classed paste, mucilage and their varieties. Glues to a certain extent dry.

The second class includes the oils. These are said to dry, but it is not by evaporation. They lose nothing, but absorb oxygen from the air. The cement weighs more after hardening than when first applied. Cements which congeal by oxydization cannot be treated in the same way as those of the first class. They require a larger time to handle. The hardening goes on from the outside inward. For example, mend a piece of porcelain with one of these cements. Test it in a few days, and although the outside will be hard the inside will not appear to have dried in the least, and will have no tenacity. Leave it for six months, and it will be very strong.

Thirdly, we have those cements which harden by cooling. These, instead of gaining their strength slowly, like those of class two, become hard at once. Shellac is a good example of a cement of this kind. China put together with melted shellac is extremely strong.

A fourth class of cements may be represented by plaster of Paris. This is the type of an extensive class, including the whole line of mortars and hydraulic cements on which depend our great engineering works, and even the houses in which we live. It forms a chemical compound combination with water first, and then more slowly hardens by drying a part of the water evaporating.

In order to use a cement successfully we must know to what class it belongs and treat it accordingly. Next, we must know how to put it on. In no case should it be used in a large quantity. The less the better is a good rule to follow.

In mortar we mingle sand, which makes the actual thickness of the lime between the stony surfaces in all cases very slight, however much mortar we may employ. In the use of glue this is not practiced or necessary. The joints made by carpenters are good examples of the minute quantity of a cement which is necessary. Place a well-made glued joint on the edge, and it is almost impossible to find the lines of glue. Its position is mainly discovered by the direction of the grain of the wood.

Intimate contact between the cement and the edges is necessary. This is not easy, on account of the layer of air which adheres to all bodies. This layer of air is what causes needles to float when carefully placed upon the surface of water.' When an object is warmed the film of air is easily moved, the hot needle sinks, and to the hot body the cement will adhere easily. It is faulty for this reason, that in gluing it is needful to have the work warmed. The rubbing of the surfaces together gets rid of the air, and then not only with glue, but with all cements, the surfaces must be pressed closely together,

Common glue has most enormous strength and adhesive powers if it is good. But to be good it must not have been injured in the making by decomposition, to which the material and the glue itself are peculiarly subject. Here the lecturer detailed at some length the process of glue making, and said that if glue was not pleasant to both taste and smell it would not be strong. If not offensive, it could be trusted to hold wood more strongly than its own fibers.

The strongest known glue is that made from the skins and sounds of fishes, and the strongest of this class is made in Lapland from the skin of a perch. The Laplanders use it in making their bows, which are both strong and durable. In making it their cold climate is greatly in their favor; here a fish skin will begin to undergo decomposition before it can be dried.

In making it the skins are put into a bladder, which answers for a water bath, and heated in water until a sort of glue results. This

glue is, as may be imagined, very elastic. Isinglass is a very strong glue, made from skins, sounds, &c., of fishes; it is very liable to be spoiled in making by overheating.

The pastes are all made from starch in some of its forms. Gluten is also used for a paste, but starch is the best. All additions of resin, &c., commonly recommended, are a damage to paste.

Dextrine, or "British gum," is of immense value in the arts as a cement. It is derived from starch by roasting or by the action of nitric acid. It was discovered by accidental overheating of starch, and its process of manufacture was for a long time kept secret. Its chief use for a long time was in the cotton manufacture. It is the standard gum for postage stamps, though it is said that gum-arabic and cheaper substitutes are used in this country.

No cement can be fire-proof which contains organic matter, since this is decomposed at a temperature about that of melting lead, or, say, 600° F. Cements containing oils will not be fire proof.

Silicate of soda, mixed with asbestos, is the nearest to a fire-proof cement. It will stand a low, red heat. It is decomposed at a bright red.

Water proof glues are made in two ways. Glue and linseed oil are recommended, but I have had better success with the mixture. The chromates may be used with glue. These, when exposed to the light, render the compound insoluble.

Aquarium cement is the best water-proof cement I know. The formula is:

Litharge	3	Rosin	1
White sand	3	Boiled linseed oil	–
Plaster of Paris	3		

The solids are to be taken by measure in powder and mixed. As it sets rapidly, the set must not be added until it is wanted for use. It is better for being put into a mortar and pounded. It hardens in three days. It will hold glass firmly, and with it glass tanks may be made without frames, if the angles are well filled with cement. It is a kind of mastic, and could be used on brick.

What is technically known as marine glue stands almost by itself. Where it can be put on hot is admirable. It is composed of India rubber and shellac, dissolved in naphtha. Some kinds are hard, some almost liquid. I have seen this glue adhere to glass so firmly as to tear the glass when plates were separated.

In the discussion which followed, Dr. Parmalee gave some interesting experiences in the manufacture of marine glue. He said its melting point was about 230°, and in making it was injured if the heat was carried above this point. In applying it care should be taken not to go above this heat, as the melting point would be raised and the strength diminished. In applying it the soldering iron may be used, but its heat must be regulated.

In answer to Dr. Parmalee, Dr. Phin said that Jeffries, the inventor, put three kinds of marine glue in the market; that the kind he himself had used was that known as "D. H. K.," and he had had no difficulty in making it adhere to glass—a point which caused some surprise.

ENGINEER'S CLUB OF PHILADELPHIA, APRIL 2, 1881.—Dr. H. M. Chance described an attempt to extinguish the Kehley Run Colliery fire at Shenandoah City, by carbonic acid gas and nitrogen. The gas was generated in an open brick furnace with reversed draught, and forced into the mine through four 3-inch pipes, by injectors supplied with steam at 60 lbs. pressure. Each pipe was supposed to supply 1,500 cubic feet per minute, or a total of 6,000 cubic feet per minute. The attempt was entirely unsuccessful, and Dr. Chance attributes its failure principally to *the impossibility of making the mine airtight*, but also considers that the gas was delivered at too high a temperature, and that it was possibly mixed with carbonic oxide. The method seems to be worthy of further trial at mines that can be made thoroughly airtight.

Mr. P. H. Baermann described briefly the construction of the Cooperstown, N. Y., Water Works, and particularly the method of laying the supply pipe extending from the pump house up the Susquehanna River into Otsego Lake, a distance of 4,500 feet. The pipe was laid from a staging carried on 120 barrels, and lowered in 108 feet sections. Up to 9 feet in depth the joints were made with dry pine wedges, and above this with lead. The end of the pipe is provided with a copper strainer, which is in 38 feet of water and 10 feet above the bottom.

A paper was also read by Dr. Chance on "Wear in Wire Ropes," showing that the cause of rapid wear is often due to the use of drums, sheaves and pulleys of insufficient size, and that a great saving might be effected by increasing their diameters; especially that of the small deflection and knuckle pulleys and sheaves. The actual wear averages 0.138 cents in slopes, and 0.053 cents in shafts, per ton, for each hundred feet of lift.

ENGINEERING NOTES

ADVICES from Vienna state that the preparatory operations having been finished, the work of boring the great tunnel through the Arlberg has now actually commenced. This tunnel will be one of the longest in the world, though not so long as that of St. Gothard. So far the operations on the eastern side of the Arlberg have progressed very favorably. The rock there found is a micaceous slate, through which the contractors find it possible to advance at the rate of from three to four meters a day. On the western side, on the other hand, the advance of the tunnel is retarded, and the operations frequently disturbed by the repeated inrush of large quantities of water. The contractors were warned before commencing the work that this was only to be expected. The geologist further advised that the tunnel should be carried through a lower stratum of rocks, which are of denser material

and watertight, but their warnings were disregarded.

THE PANAMA CANAL.—The *Panama Star and Herald* of February 3rd, says: "On Saturday afternoon, January 29, 1881, the French steamer Lafayette arrived at Colon with MM. Armand Reclus, G. Blanchet, and about forty other gentlemen, who are to be employed on the Panama Canal. For the present, and it is presumed permanently, the Canal headquarters will be in Panama, although Colon will be the main point for distribution of supplies, &c., for the work. The expedition is divided into two distinct sections or departments. M. Reclus is the general agent, with full powers from the Canal Company over all matters which may require his attention and decision on the isthmus. M. G. Blanchet is director of the canal works. It is understood that the work of the various sections and commissions is to be begun at once and pushed on with energy. It will relate principally to the exact location of the line for the proposed canal, clearing away the timber, brush, &c., thus opening up the country through which the excavation will be made; arranging matters of titles for right of way, buildings, &c., and the general land grants of the company, and other matters of a preliminary character which must necessarily precede the commencement of the actual work. A year or more must necessarily elapse before the employment of machinery will be necessary or possible, and in the meantime the number of laborers which will be needed will be comparatively small. The demand can be easily supplied at present, or for some time to come, on the isthmus or in the near neighborhood, and any great immigration of mere bone and muscle seeking employment in ordinary canal work is, for the present, unnecessary."

RAILWAY NOTES.

THE FIRST RACK RAILWAY IN PRUSSIA.—BY O. SARRAZIN.—The rich lead and silver mines of the Friedrichshagen Consolidated Company of Oberlahnstein are situated between Ems and Lahnstein, about 1½ mile from the banks of the Lahn. The company employs nearly one thousand work people, male and female, and in 1878 raised 14,000 tons of ore, which had to be transported at the rate of 46 tons a day down the valley to the river, there to be conveyed in barges to its destination. The system of land carriage being no longer equal to the requirements of the mine, it was determined to make a private railway on the Riggenback system. The line, which was opened on the 8th of November, 1880, is partly ordinary and partly rack railway. The difference of level between the two termini is 384 feet, which had to be surmounted in a length of 8,200 feet, thus giving 1 in 24.4 as the mean gradient. The steepest part worked by adhesion is 1 in 20.5, and by the rack rail 1 in 10. The racked portion is altogether 1,968 feet long, divided into three inclines of respectively 262, 1,165, and 541 feet each. The width of the gauge is 1 meter (3.28 feet). The curves on the racked portions are everywhere of a radius of 475 feet. At both ends, and at the middle of the line for the dressing floors, are sidings reached by switches of the ordinary construction, and a turntable affords access to the tracks laid in the works below. The teeth of the rack are 3.9 inches from center to center; it weighs 90 lbs. per yard, and cost about 22*s.* per yard at the works. The rails, 3¾ inches high, weigh 50 lbs. per yard, and cost £8 10*s.* per (metric) ton. In spite of the generally economical nature of the line, it was impossible to avoid some heavy works in cuttings and banks, the excavation in rock amounting to more than 15,000 cubic yards. It was also necessary to cross the line of the Nassau railway, the many streams in the valley, and the road leading to the Friedrichshagen works. Some of the bridges are of iron, but the greater part are of masonry. The working stock is at present limited to one locomotive and eighteen wagons. The engine, constructed in the works of the Swiss central railway at Olten, weighs 10 tons, or with fuel and water, 11.8 tons, and cost £1,120.

Its load is 10 tons up to the mine, and 18 tons down to the valley. The wagons weigh 0.9 ton each, and carry 2.5 tons. They are provided with brakes, and cost £32 10*s.* each. The greatest speed is six miles an hour. The line was begun in April, 1880, and was only seven months in making. It cost, including working stock, 150,000 marks (£7,500) or 60,000 marks per kilometer (£4,800 per mile), which compares favorably with similar lines in Switzerland, costing from 140,000 to 97,000 marks per kilometer. This makes the tenth railway in Europe on the Riggenbach system, the others being at Arth-Rigi, Vitznau-Rigi, Rohrschach-Heiden, and quarry lines at Ostermundingen and Laufen, and the Ruti line in Switzerland; Kahlenberg, and Schabenberg in Austria-Hungaria; and the Wasseralfingen line in Wurtemburg.—*Wochenblatt für Architekten und Ingenieure.*

ORDNANCE AND NAVAL.

THE NEW ARMORED CRUISER.—Active measures are being taken at Portsmouth for commencing the new armor-clad cruiser mentioned in the Navy Estimates for 1881-2. She will be constructed in No. 12 dock, within the extension works, a plan of building which has many advantages over the method usually adopted of building on a slip. All the weights, instead of having to be raised, will be dropped to where they are wanted, and when the ship is completed she will be simply floated out of dock, instead of having to be launched into the water by the expensive and complicated method adopted in the case of the *Inflexible*. The only drawback is the exposure to the weather, and this will be remedied by some temporary shelter. The length of the ship has been increased to 315 feet between perpendiculars, while her breadth is 61 feet, and her mean draught 24 feet 3 inches. About 120 tons of material, consisting of angle

steel plates and rivets have already been demanded. A disposition of butts and edges of the bottom plating has also been submitted by the officials at Portsmouth, and approved by the Construction Department at the Admiralty, and every effort will be made to begin the ship as early as possible in the ensuing financial year.

NEW STEAM PINNACE.—A boat of a very novel design has been successfully tried in the Solent, and submitted to the dockyard officers at Portsmouth for their approval. It was built by Mr. S White, of East Cowes, and in size, shape, and general construction is almost an exact copy of the 48 feet steam pinnaces which he has supplied to the navy for guard and other purposes. The distinguishing feature of the new boat is the manner in which the deadwood and keel have been cut away to the extent of about one-half of its length, by which a free flow of water to the screw is secured. The advantage, however, does not consist in any accession of speed while going ahead, which remains the same, but in a considerable gain to speed in going astern, which it can do as rapidly as ahead, and in the remarkable handiness which the new principle confers in going round. A very small acquaintance with vessels is sufficient to show that when the helm is put hard over, the stem of a boat makes little forward progress, but is made the pivot upon which the stern revolves. As the stern is invariably the more deeply immersed, the result is that, in turning, the craft is compelled to force back a wall of water, which retards the boat in going round, throws great strain upon the rudder and gear, and increases the work of the engines. In cutting away the deadwood, the resistance of the water is reduced to a minimum as it escapes under the quarter, and the pinnace was found on trial to turn a complete circle under full power in one and a half of its whole length. The new design also enables the craft to stop almost dead, its way being arrested by a supplementary rudder, which is placed abaft the screw, and is worked simultaneously with the ordinary rudder outside. By placing this rudder at right angles with the keel, it acts as an effectual brake, and arrests the way of the craft. It was feared that the reduction of the depth aft would have the effect of diminishing the stiffness of the pinnace in turning, but practical tests have proved that the difference is scarcely appreciable. The great drawback which has hitherto attached to torpedo craft is the size of the circle which they require in turning, a defect which has been partially remedied by fitting a drop rudder forward. Should Mr. White's plan be found applicable to them, their activity in the water will be greatly increased by its adoption. The little craft was put through a severe trial. The behavior of the pinnace has answered every expection, while its remarkable handiness surprised the officers in charge. At a previous trial the boiler pressure, with closed stokehole, was 120 lbs. (the same as in the torpedo craft), while the air-pressure from the fans equaled 4 inches of water; the revolutions per minute were 435, and the horse power indicated 90. Six runs were made, the mean speed ahead being 12.356 knots per hour. Two runs were afterwards made with the screw going astern, the result giving an average speed of 10.14 knots, the revolution being the same. The steering qualities of the boat were next tested. when the absence of the after deadwood gave some remarkable results, the boat circling to starboard and to port in 30 seconds, or one-third the usual time, in a space having a diameter of 72 feet. With the engines going astern the pinnace turned in 1½ minute. As the propeller shaft revolves in solid water, and is only connected with the quarters by a bracket, there was a remarkable absence of vibration. The two rudders are simultaneously actuated by means of gearing and a double worm, which effectually locks the rudder and thus enables the wheel to be left to itself.—*Times.*

BOOK NOTICES.

PUBLICATIONS RECEIVED.

ANNUAL REPORT OF THE STATE GEOLOGIST FOR THE YEAR 1880. 8vo. Paper. Trenton.

A LECTURE on the Progress of the Works of Completion of the New Improved Bed of the Danube at Vienna, and the lessons taught thereby; by Sir Gustav Wex. With five sheets of drawings. Translated by Maj. G. Weitzel, U. S. A. 8vo. Pamphlet. Government Printing Office. 1881.

THE WORKSHOP. No. 4, for 1881. New York: E. Steiger & Co.

REPORT OF THE U. S. WEATHER BUREAU for February.

NOTES ON RANKINE'S APPLIED MECHANICS. By Geo. I. Alden, B. S. Hartford. For sale by D. Van Nostrand. Price $1.75.

A small book for the use of students is here provided by the Professor of theoretical and applied mechanics in the Worcester Free Institute.

Students who have found difficulty in their study of Rankine will welcome this aid.

The so-called notes are given as supplementary to separate numbered articles of the applied mechanics.

The author has also added the graphic solution of a truss, and an investigation of the Peaucellier cell.

ELECTROTYPING—A PRACTICAL MANUAL. By J. W. Urquhart, C. E. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price $2.00.

To say that this book is very well printed on tinted paper, and that the wood cuts, twenty-six in number, are mostly well executed, is to enumerate its chief merits.

It contains some valuable hints to practical workers, and devotes much space to the rudiments of electro-chemistry, but in either part it is too sketchy to prove of any special value to either the general reader or the artisan.

MEASURES, WEIGHTS AND MONEYS OF ALL NATIONS. By W. S. B. Woolhouse, F. R. A. S. London: Crosby Lockwood & Co. For sale by D. Van Nostrand. Price 80 cents.

This is the sixth edition, enlarged, of a cheap form of a valuable book. It is of a convenient size (Weale series), and the tables are well selected and well arranged.

THE GAS ENGINEER'S DIARY AND TEXT BOOK FOR 1881. By G. E. Wright and Wm. S. Mason. Birmingham: Office of "Gas Engineer." For sale by D. Van Nostrand. Price $1.00.

The portion of this work which is termed the "Literary Section" will probably prove to be the valuable portion to gas engineers on this side of the Atlantic. This section is composed of several articles by different writers, specially prepared for this work and devoted to gas engineering and gas manufacture

A portion of the work is devoted to tables, formulas and statistics of special use to the working engineer.

RIVER BARS, THEIR FORMATION AND TREATMENT. By I. J. Mann. London: Crosby Lockwood & Co. For sale by D. Van Nostrand Price $3.00.

This thin octavo of seventy-five pages deals with admirable conciseness with an important subject.

The table of contents is as follows:

Chapter I. Bar Formation.
II. Wave Action.
III. Currents and Scour.
IV. Dublin Bar.
V. Dublin Harbor Improvement Schemes.
VI. Dublin Bar—Treatment by Induced Tidal Scour.

The illustrations, twenty-three in number, are good.

THE COAL FIELDS OF GREAT BRITAN. By Edward Hull, LL.D., F. R. S. London: Edward Stanford. For sale by D. Van Nostrand. Price $6.40.

This is of local rather than general interest. The descriptions of the geography and geology of the coal districts are exceedingly full and the maps are very fine.

A brief sketch of the coal fields of India and of North and South America closes the volume.

MINE DRAINAGE. By Stephen Michell. London: Crosby Lockwood Co. For sale by D. Van Nostrand. Price $6 00.

This a practical treatise on underground pumping machinery, with complete descriptions in detail of a large number of the best known engines

The contents are classified as:

Rotary Horizontal Engines, Non-Rotary Horizontal Engines, Rotary and Non-Rotary Vertical Engines.

As a book of reference for the mining engineer, the work must be of exceeding value.

A TECHNICAL TREATISE ON SOAP AND CANDLES, WITH A GLANCE AT THE INDUSTRY OF FATS AND OILS. By R. S. Cristiani. Philadelphia: Henry Carey Baird & Co. For sale by D. Van Nostrand. Price $6.00.

In this, as in all complete works on subjects relating to chemical technology, the chemical and physical properties of all the raw materials are fully discussed, and as in this case the number of substances is considerable, a large space is devoted to the natural history of an interesting class of bodies, which will render the book of value to many who are not interested in the processes of manufacture, to which the volume is otherwise devoted.

The illustrations are numerous and good, and serve to describe with great minuteness the latest improved methods.

IMAGINARY QUANTITIES, THEIR GEOMETRICAL INTERPRETATION. Translated from the French of M. Argand. By Prof. A. S. Hardy. For sale by D. Van Nostrand. Price 50 cents.

This essay forms No. 52 of the Science Series, and is presented just as it appeared in the pages of this magazine.

It is of the class of essays which most students, who take delight in mathematics, will read with pleasure and profit. It will interest more readers than do the heavier articles of the mathematical journals, inasmuch as the subject is one presented to the student almost at the beginning of his algebra.

The notes of the translator will, we think, be read with quite as much interest and profit as the original essay.

SYNOPSIS OF THE FRESH-WATER RHIZOPODS. Compiled by Romyn Hitchcock, F. R. M. S. New York: Romyn Hitchcock. For sale by D. Van Nostrand. Price 75 cents.

This is practically a descriptive catalogue of this interesting group of Protozoa. The characteristics of the genera are given with satisfactory fullness; then follows a list of species with the principal features described, after which each species is described with great minuteness.

The book will prove a great aid to students who collect microscopic organisms, and, indeed, is calculated to stimulate many to begin such work.

ELECTRIC LIGHTING BY INCANDESCENCE, AND ITS APPLICATION TO INTERIOR ILLUMINATION. With 96 illustrations. By William Edward Sawyer. 8vo. New York: D. Van Nostrand. 1881. Price 2.50.

This is a book of great practical value to all who wish to understand the subject. The style is exceptionally clear and comprehensive. We, of course, perfectly understand that the book is written in order to introduce the Sawyer system of lighting to the general public; therefore, the closing words of the preface, implicitly carried out as they are throughout the whole book, appear noble by comparison with many books of the same order. We quote: "Those who expect to find them devoted to criticism of the labors of other experimentalists will be equally disappointed. In

the position of an impartial student and observer, I have sought less to indicate defects than to exhibit accomplishments."

Of the work, fifty-three pages are devoted to a full description of all the types of dynamo machines, of which only ten describe the Sawyer. Thirty-three engravings fully illustrate this portion of the book. A view of each machine, with diagrams of internal construction in detail are given, and explained in the text with unusual clearness and perspicuity. Especially is this the case in the winding of the wires in the various methods of construction, so that any intelligent mechanic could, from the drawings and text, easily construct any of these machines. The various physical laws are introduced incidentally, as occasion requires. The writer has not seen any book from which so much detail can be learned as from this.

As the Sawyer light is of the incandescent class, of course the book treats of that class in particular, devoting sixty-one pages of text and thirty-two engravings to the lamps and carbons, nearly one-half of which is taken up with other patents. The details of the Edison alone are illustrated by seven diagrams, giving the best idea of the process of manufacturing the Edison lamp we have seen; also, a fine view of the Maxim form. As a part of the lamp, twenty pages and five plates are devoted to the manufacture and preservation of carbons. A page diagram is given of the Sprengel pump, as used by Edison and others. All conflicting patents appear to be given, with dates. The chemical notes beginning page 105 are excellent. His remarks, page 103, upon the comparative cost of arc and incandescent lighting present the subject so clear that we quote: "Light by incandescence is considerably more costly than light by the voltaic arc, when the volume of light obtainable is the sole consideration. The same expenditure of power that will produce a light of 1000 candles by the voltaic arc will not produce, on an average, more than half or one-third as much light as incandescence in a divided circuit. It should not, however, be forgotten that the power of any light decreases as the square of the distance from it, and that one-fourth of the light of the arc, distributed at four or five appropriate points, thus reducing the power of each light to $\frac{1}{16}$ of that of the voltatic arc, will give substantially as good a general illumination as the arc. The incandescent light is whatever may be desired. The arc light is necessarily a powerful one. The objection to it, if used without a shade, is its great intensity and ghastly effects; and in order to obviate these defects, glass shades of more or less opacity are employed, which, according to tests, involve a wastage in light of,

With ground glass.....	30 per cent.
With thin opal glass.....	40 "
With thick opal glass.....	60 "

In some cases wastage is nearly 75 per cent."

Experiments in France on the Jablochkoff, with the necessary opalescent globes, "it is found that only 43 per cent. of its full power is available." "It is proper to remark that the light of the incandescent carbon is very unlike that of the voltaic arc. Its characteristics are the characteristics of daylight; and this is true to such an extent that, from its soft and agreeable nature and absence of glaring effects, the degree of illumination afforded is not always readily appreciated." Besides, incandescent lights *do not* require shades.

Chapter IX. treats of "the division of the current and light;" a most interesting chapter, because of the widely different opinions of physicists upon the subject. This should be read by all who are interested, as the author states his case and calculations clearly. If verified by future experiment they are of great value, but only actual experiment can decide.

Chapter X is devoted to a description of the Sawyer regulator, called here the switch—a most important part of the system, as by it the light is almost instantly turned up or down, giving any degree of intensity of light as required by the person using it. The subject is illustrated in ten perspective and six diagram views, including the current regulator, one being a fine view of the Maxim governor. While these regulators admirably perform their functions, he is careful, in perfect candor, to inform the reader (page 149) that, "By means of these regulators the changes in the circuit occasioned by the Sawyer switches for graduating the light are instantly balanced. But the fact remains that as much power is expended in driving the generator when there are a few as when there are many lamps in a circuit, and in a general distributing system, where economy is the prime consideration, such regulators, however perfect in their operation, can have no practical application." We venture to remark that this is not a peculiar defect of the electric light, but is a foundation principle governing every other industry.

Chapter XI is devoted to the consideration of the Sawyer patent for lighting the buildings in the blocks of a city by electric lights. The history, plans, meters, switches, etc., requisite are fully set forth in the text and eleven diagrams. It also deserves careful study. In it the "Niagara Falls problem" is discussed at length, and, to our mind, settles that question.

The last chapter is devoted to the commercial aspects of the subject—that omnipotent question, "Will it pay?" This chapter involves so many points, exhibits so many tables and calculations, which must be most carefully studied before an opinion can be given, that we have not time this month to devote to it. It is in print, in the book, for all interested to criticise.—*Journal of Franklin Institute.*

SHOCK'S STEAM BOILERS.—In the issue of March 4, 1881, *The Engineer*, of London, devotes nearly a column and a half to a review of the recent work on "Steam Boilers," by Engineer-in-Chief W. H. Shock, U. S. N. The reviewer calls it "the most important treatise on boiler engineering with which we are acquainted," and gives great praise to the illustrations, paper, printing, binding, etc. He says: "The plates are working drawings, which only require to be enlarged to be fit to send into the shops, and in the matter of constructive de-

tails they show much that will be found novel and useful by English engineers." It is not, however, clear to the mind of the American engineer why he should call the bracing of the rectangular boiler, shown on plate 18, "a curious example" of "misplaced ingenuity." On this plate the best American practice of bracing rectangular boilers is illustrated, and the devices are in no way novel; but it is true that English practice, even in so-called first-class work, is, in many respects, very inferior to this. While summing up his opinion of the book in the last paragraph, the critic calls it "the most complete treatise on the marine boiler ever written," in which there is little to call for adverse criticism; and says further on, "it brings our knowledge of it (boiler engineering) down to the latest date and the questions which may be asked, and the answers to which cannot be found between the covers, must be few and far between," he makes the unreasonable complaint that it does not give a satisfactory answer to *all* the perplexing questions which now disturb the mind of the marine engineer. The critic finds fault with the writer for following closely in the footsteps of Rankine, in the chapters on combustion, transmission of heat and evaporation; but he does not point out a single fact which requires correction, nor does he indicate a safer guide. It is hardly fair in the critic to give it as his opinion that the investigation of the laws governing the draught of chimneys is simply inserted "to give an air of erudition to the work." If he had studied this chapter carefully he would have found that a number of very important conclusions are drawn from this investigation. From the fact that the rules given in the book regarding the management of boilers do not differ essentially from English practice, the reviewer concludes that they are directly derived from it. This may be pardonable in an English critic. The reviewer desires fuller information regarding the use of steel for boilers. He should, however, be aware of the fact that many questions relating to this subject will necessarily remain unanswered for years to come. For the enlightenment of the critic, we add that steel boilers have been introduced into United States Naval vessels since the last three years and have given the most satisfactory results. This is due, no doubt, in a great measure, to the superior quality of the material employed, which is entirely free of the defects found in many English steels, that cause so much trouble to the English boilermaker. It will be seen that the few unfriendly criticisms, seasoning the high praise given to the book, are mostly trivial and unreasonable; the critic has been looking for new theories, but the author has given nothing but established facts, because the latter are more needed than the former.—*Army and Navy Register.*

MISCELLANEOUS.

GEOGRAPHICAL NOTES.—On Tuesday night, at the Royal Institution, Mr. Edward Whymper described his ascents of Chimborazo and Cotopaxi to a distinguished audience. While purely athletic mountaineers had his sympathy in the practice of mountaineering as a sport, Mr. Whymper confessed that his sympathies were much more with those who employed their brains as well as their muscles. His journey to the Andes was to be one of work, and all its arrangements were devised so as to economize time to the uttermost. In observations for altitudes and position, in studying the manners and customs of the country, in photography and sketching, in the collection of objects of interest, from beetles on the summits of mountains to antiquities buried in the ground, he found quite sufficient to occupy his time. From Bodegas the party was composed of two Swiss mountaineers, the cousins Carrel, of Val Tournache, Mr. Perring, some muleteers, and their teams. When they reached the summit of Chimborazo, on the 3rd of January, after a most arduous climb, they found the wind blowing at the rate of 50 miles an hour, from the northeast, and driving the snow before it. With extreme difficulty, a reading of the mercurial barometer was effected. The mercury fell to 14.1 inches with a temperature of 21° Fahr. This being worked out, in comparison with a nearly simultaneous observation at Guayaquil, gave 20,545 feet for the height of Chimborazo. They began the descent at 20 minutes past 5, with scarcely an hour and a quarter of daylight, and reached their camp (about 17,400 feet above the sea level) about 9 P. M., having been out nearly sixteen hours, and on foot the whle time. Passing from an extinct to an active volcano, Mr. Wymper next gave an account of his journey to the crater of Cotopaxi. Observing with the telescope, during an enforced stay at Machachi, that much less smoke or vapor was given off at night than by day, he resolved; if possible, to pass a night on the summit. On the 18th of February the party got to the edge of the crater, having passed almost the whole way from their camp at a height of 15,000 feet to the foot of the final cone over snow, and then over ash mixed with ice. The final cone was the steepest part of the ascent, and on their side presented an angle of 36 degrees. When they reached the crater vast quantities of smoke and vapor were boiling up, and they could only see portions of the opposite side at intervals, and the bottom not at all. Their tent was pitched 250 feet from the edge of the crater, and during a violent squall the india-rubber floor of the tent was found to be on the point of melting, a *maximum* thermometer showing a temperature of 110 degrees on one side of the tent and of but 50 degrees on the other; in the middle it was 75.5 degrees. Outside it was intensely cold, and a thermometer on the tent cord showed a *minimum* of 13 degrees. At night they had a fine view of the crater, which has from a diameter north to south of 2000 ft., and from east to west of about 1500. ft. In the interior the walls descend to the bottom in a series of steps of precipice, and slope a good thousand feet, and at the bottom there was a nearly circular spot of glowing fire, 200 feet in diameter. On the sides of the interior, higher up

fissures, from which flickering flames were leaping, showed that the lava was red hot a very short distance below the surface. The height he found to be 19,600 feet. The party remained at the top for twenty-six consecutive hours, sleeping about 130 feet below the loftiest point. At first they had felt the effects of the low pressure of the atmosphere, and again, as at Chimborazo, took chlorate of potash with good effect. All signs of mountain sickness had passed away before they commenced the descent, and did not recur during the journey. Nearly five months later Mr. Whymper returned to Chimborazo, and from a second reading of the barometer at 14.028 inches, with a temperature of 15 degrees Fahrenheit, he made the height 20,489 feet, the mean of the two readings giving 20,517 feet. While on the side of Chimborazo he witnessed a magnificent eruption of Cotopaxi, ashes rising in a column 20,000 feet above the rim of the crater and then spreading over an area of many miles. Prof. Bonney had submitted the ash to microscopic examination, and found that the fineness varied from 4,000 to 25,000 particles to the grain in weight, and from observation of the area over which the ash fell Mr. Whymper calculated that at least two million tons must have been ejected in this one eruption.

A TELEGRAM was read at a recent meeting of the French Academy of Sciences from M. de Brazza, who has been conducting an exploration in the region of the Ogowe and Congo, West Africa. Quite recently a French station has been founded in the upper course of the former river in connection with the International African Association. In July last, M. de Brazza informs the Academy he reached the Congo from this station on the Ogowe, between the river Inpaka Mpania and the river "Lawson Afrisi." Gaining the favor of King Makoko he pacified the tribes on the right bank of the Congo, and peacefully descended the river in a canoe. On October 3 he founded the station of Ntamo Ncoma on land ceded by King Makoko on the right bank of the Congo. M. de Brazza surveyed the route between the Ogowe and Congo; it is twelve marches in length, over a plateau of an average height of 800 meters. The country is healthy, and the population dense and peaceful. In November last M. de Brazza arrived at Mdambi Mbongo, the advanced post of Mr. Stanley, whom he met, and with whom he reached the latter's headquarters at Vivi on November 12. If the new station can be maintained and victualed, it is no doubt well chosen as a starting point for further discovery, for both north and south of it, there are large regions of which he knew nothing.

AT the meeting of the Geographical Society on Monday last, Mr. E. Delmar Morgan gave some account of his journey last year to Semiretchia and the town of Kulja. Being unable to make use of the more southern line of communications, Mr. Morgan traveled by the northern post road from Orenburg to Troitsk and Petropaulofsk, and thence to Omsk and Semipalatinsk. He then struck southwards to Sergiopol, where he was detained three weeks owing to the southern road being blocked by snow. He afterwards went to Kulja for a short time, and he also made some excursions to Issyk-kul and other places of interest. In the course of the discussion which followed the paper, Mr. Ashton Dilke, the only other Englishman who has visited Kulja, gave an interesting account of his experiences in that region a few years back.

M. TARRY, a member of the French Commission for Trans-Saharan Communications, is stated to have discovered in the south of Wargla the ruins of a large city called Cedrada, which had been entombed by sands of the desert. This city is placed in the Valley of Wed Mya, and in the vicinity of a number of sources which in former centuries watered thousands of palm trees. Orders have been sent to procure a set of sounding apparatus, and it is expected a large quantity of pure water will be extracted from the earth. M. Tarry published an appeal to the local papers in order to obtain from the Government the foundation of a colony in this remote region.

SANITARY HOUSES.—The Society of Arts propose to award medals for plans showing the best sanitary arrangements in houses built in the metropolis, such plans to be exhibited in the Society's rooms, Adelphi, in June, 1881, and to be sent in on or before 12th May, 1881. One silver medal will be awarded for the best sanitary arrangements carried out and in satisfactory working in a house let out in tenements to artisans for which a weekly rental is paid. One silver medal for the best sanitary arrangements in actual satisfactory working in a house of the yearly rental of from £40 or less to about £100 in value. One silver medal for the best sanitary arrangements in actual satisfactory working in a house of the yearly rental of £200 and upwards to any amount. The houses must be open to the inspection of the judges, who, in considering their award, will be guided by the suggestions of plans for main sewerage, drainage and water supply, made under the Public Health Act, 1875. The houses must have been in actual occupation within the last three months, and a certificate must be given by the occupiers, on a printed form, stating the satisfactory working of all the sanitary arrangements, such form to be obtained at the Society of Arts. The houses may be old, fitted with modern sanitary arrangements, or may be new. They must be within the metropolitan area of the Board of Works. The sanitary arrangements must include the conditions for good water supply, drainage, warming and ventilation of the house, and precautions taken against frost. The medals may be awarded to the occupiers of the houses or the lessees, or the owners. The plans must consist of a ground plan and sections, to the scale of not less than 1 inch to 5 feet; details not less than 1 inch to the foot. The plans may be accompanied by specifications.